AD NUMBER

AD810310

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

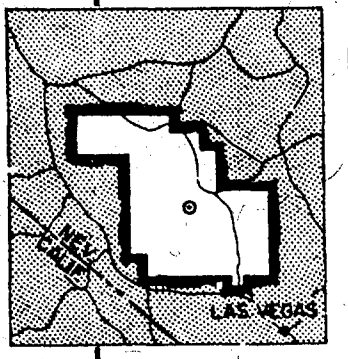
Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; JAN 1961. Other requests shall be referred to Controlling officer; Air Force Special Weapons Center, Kirtland AFB, NM.

AUTHORITY

DNA notice, 5 Dec 1979

WT-1512

OPERATION PLUMBBOB



NEVADA TEST SITE
MAY-OCTOBER 1957

Test Group 57, Program 73

MONITORING AND DECONTAMINATION TECHNIQUES FOR PLUTONIUM FALLOUT ON LARGE-AREA SURFACES

Issuance Date: March 3, 1967

AIR FORCE SPECIAL WEAPONS CENTER,
KIRTLAND AIR FORCE BASE
ALBUQUERQUE, NEW MEXICO

WT-1512

Operation Plumbbob--Test Group 57, Program 73

MONITORING AND DECONTAMINATION TECHNIQUES FOR PLUTONIUM FALLOUT ON LARGE-AREA SURFACES

By

J. L. Dick, Maj, USAF
T. P. Baker, Jr., 1/Lt, USAF

Air Force Special Weapons Center
Kirtland Air Force Base, New Mexico
January 1961

ABSTRACT

Plutonium contamination is possible when certain weapons are subjected to nonnuclear destruction. Procedures for monitoring, control, and decontamination of plutonium from land and hard-surface areas are described.

The most effective means of land-surface decontamination are listed in order of decreasing efficiency as follows: plowing; oiling and scraping; leaching with 0.3 inch of water and scraping; leaching with 0.3 inch of water; and leaching with 0.3 inch of water-Alconox solution. Efficiencies were generally above 86 percent.

The most effective means of hard-surface decontamination are listed in decreasing order of efficiency as follows: sand-blasting; water-detergent scrubbing; water-detergent hosing; water hosing; water scrubbing; steam cleaning; and vacuuming. Efficiencies were all above 66 percent, with the majority above 95 percent. Hard-surface areas included concrete, asphalt, plate steel, aluminum, galvanized roofing, tarpaper roofing, painted wood, unpainted wood, glass, brick, stucco, wood shingles, and asbestos shingles. Flats of grass were also exposed.

All vehicles and test equipment used in the contaminated area were readily decontaminated.

Sample calculations of approximate radiological hazards to man were made for the shot configuration and meteorological conditions peculiar to the Test Group 57 experiment. First, provisional estimates of the acute exposure (from cloud passage) 675 feet from ground zero were that an initial lung burden about three times the maximum permissible level would have resulted, but that integrated lung dose would approach continuous irradiation at the maximum level after about 105 days and thereafter would be lower.

Second, similar rough estimates were made for exposures of personnel entering the contaminated area after the shot. With entrance delayed 3 or more hours after detonation and the assurance of no resuspension forces beyond reasonable winds, a human could remain for an unlimited time in areas contaminated as heavily as 5000 $\mu gm/m^2$. Since this represents a special set of circumstances, decontamination certainly to $\leq 1000\ \mu gm/m^2$ is recommended for any real accident area. For complete rehabilitation, much more complete decontamination would be needed.

ACKNOWLEDGMENTS

The authors wish to acknowledge arduous and exacting field work for this program performed by the following personnel: 1/Lt M. V. Harlow, 1/Lt B. B. Boecker, 1/Lt R. D. Morris, 2/Lt J. B. O'Laughlin, M Sgt W. P. Schaus, A/1C R. H. Bentley, A/1C Brown, and A/1C L. J. Talomo of the Air Force Special Weapons Center, Kirtland AFB, New Mexico; Dr. W. R. Eckelmann of Columbia University; and Capt W. T. Burnham, 1/Lt R. V. Garcia, and the men of the 50th Chemical Platoon (Service), U.S. Army, Camp Desert Rock, Nevada.

Appreciation is expressed to Mr. Dean Meyer of the Los Alamos Scientific Laboratory for furnishing the extended area sources used in this project.

Also, appreciation is due Col E. A. Pinson and Capt R. F. Merian, formerly of the Air Force Special Weapons Center, Kirtland AFB, for work and guidance in the program, and for their coauthorship of ITR-1512, forerunner of this report.

CONTENTS

CONTENTS (Continued)

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

TABLES

Chapter 1

INTRODUCTION

1.1 OBJECTIVES

Objectives of Program 73 were: (a) to determine the effectiveness with which plutonium contamination can be removed from several types of hard surfaces; (b) to determine the effectiveness of decontamination and fixing methods on contaminated land areas; (c) to analyze the acute radiological situation with regard to personnel exposed to the passage of the cloud; and (d) to analyze the chronic radiological situation affecting personnel living for long times in areas of high-plutonium surface concentration.

1.2 BACKGROUND AND THEORY

Modern nuclear weapon development has presented the problem of possible plutonium contamination as a result of nonnuclear destruction of certain weapons. In the event that such a weapon is involved in an aircraft accident or jettison, there is a possibility that the weapon will burn or that the high explosive will detonate. In these cases, plutonium will be dispersed over the surrounding area in the form of a fume of fine particulate matter.

Possible existence of the alpha contamination problem was first reported following the one-point detonation of a device containing high explosive and a La^{140} tracer in lieu of Pu^{239}.[1] A subsequent investigation was carried out during Project 56.[2] In this project, a device containing plutonium was subjected to one-point detonation. Air sampling and surface monitoring were conducted to determine magnitude of air and surface plutonium levels.

Documentation of this event was limited and the data appeared to indicate that the acute hazard, i.e., during cloud passage, was much smaller* than the chronic or rehabilitation hazard. The chronic exposure problem is much more difficult to define. Many variables are encountered when an attempt is made to fix the magnitude of the exposure problem as a function of concentration on the surface, of quantity resuspended, and of amount finally taken into the body via inhalation. The Los Alamos Scientific Laboratory has attempted to determine a reasonable surface contamination below which no health hazard is anticipated.[3] Although data used were limited, a permissible surface contamination level of 100 $\mu gm/m^2$ was suggested.

*This judgment was reversed by the much more complete study of the problem by Test Group 57.

Since the Air Force engages in operational activities in which nonnuclear destruction of weapons can most likely occur, the Air Force Special Weapons Center prepared a publication[4] which discussed this problem. This report has been revised[5] and an unclassified report[6] has been published which outlines control and cleanup procedures for handling plutonium contamination.

Test Group 57 undertook to better define the many parameters involved in this type event, as well as to better describe the possible attendant hazard to humans.

Chapter 2

PROCEDURE

2.1 DECONTAMINATION PAD ARRAY

Prior to the scheduled date of detonation, an area 2000 feet wide, extending from 200 to 1200 feet north of ground zero, was selected for location of contamination pads. Meteorological requirements established for time of detonation were expected to provide high-level plutonium fallout on this area. Hard test surfaces consisted of both concrete and asphalt pads, one each 24 by 50 feet, seventeen each 10 by 10 feet, fifty-eight each 2 by 2 feet, and approximately twenty 2- by 2-foot pads of each of the following materials: plate steel, aluminum, galvanized roofing, tarpaper roofing, painted wood, unpainted wood, glass, brick, stucco, wood shingles, and asbestos shingles. At each 2- by 2-foot pad location, one pad was placed horizontally and a second placed vertically in random compass orientation. In addition, twenty 2- by 2-foot pads of grass were placed in the area.

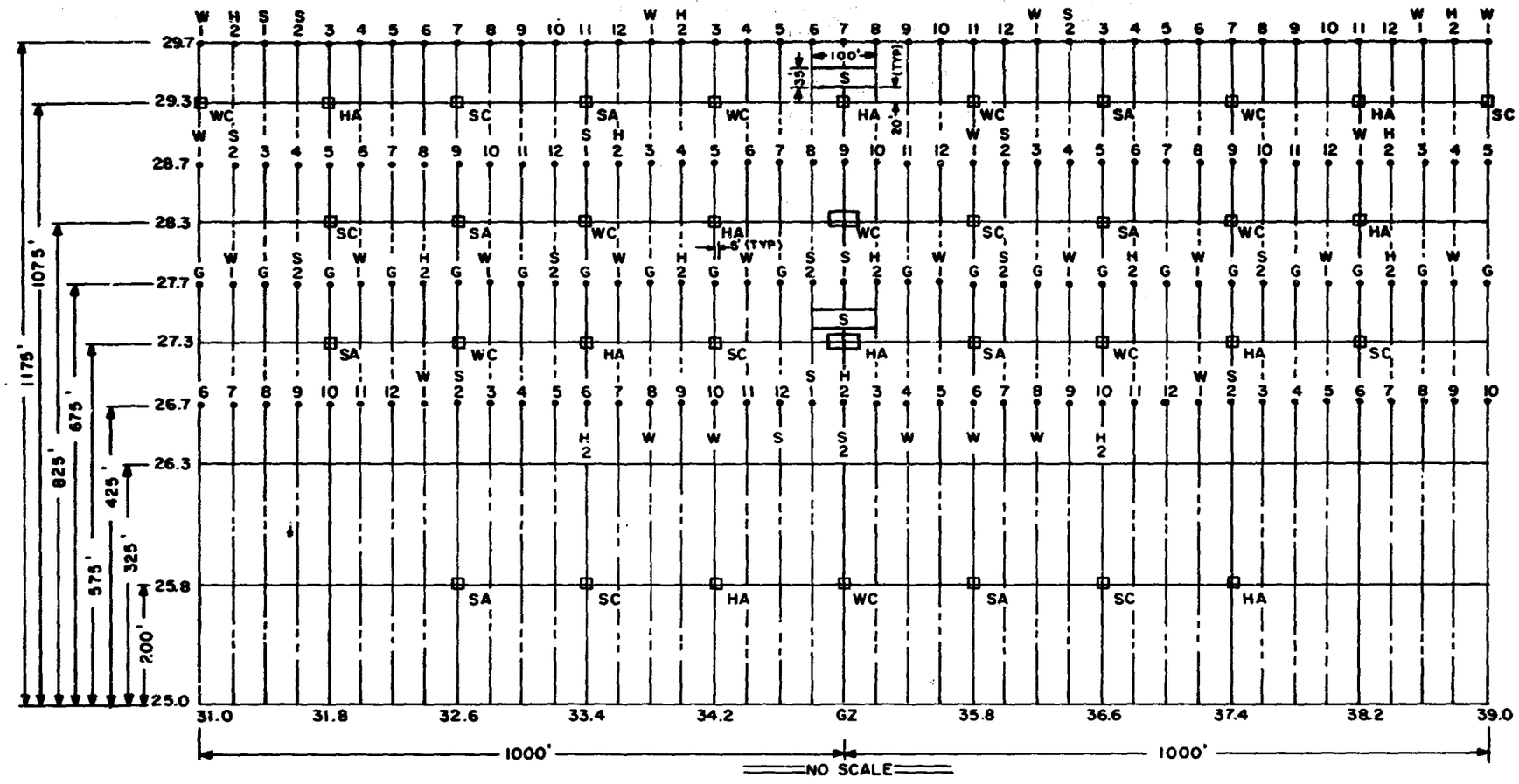
Two 35- by 100-foot plots of ground, located 700 and 1100 feet due north of ground zero, were prepared by removing vegetation and leveling. Details of contamination pad positioning are shown in Fig. 2.1. Photographs of typical pad stations are shown in Figs. 2.2, 2.3, 2.4, and 2.5.

2.2 INSTRUMENTATION AND EQUIPMENT

Instrumentation consisted of gas flow proportional alpha counters, high- and low-volume air samplers, cascade impactors, microscope slides, soil sampling units, and recording anomometers.

2.2.1 Counters

Twelve Model PAC-1G gas flow proportional alpha counters, manufactured by the Eberline Instrument Company, Santa Fe, New Mexico, were used for surface monitoring. This instrument (Fig. 2.6) consists of a gas flow proportional chamber, a transistorized pulse amplifier, and a one-shot multivibrator followed by an integration circuit. The meter readout was calibrated to a maximum range of 100,000 cpm. The instrument was calibrated on middle and high ranges, using 5- by 10-inch distributed sources of 174 and 1790 dpm/cm^2, respectively. The low scale was calibrated against a known point source. All sources were prepared by the Los Alamos Scientific Laboratory. Detailed evaluation of the PAC-1G and several other alpha surface monitoring instruments for field use is described in another report.[7]



KEY

- • 2' x 2' PODS (ONE HORIZ, ONE VERT, 1 THRU 12)
- W1 S1 CONCRETE - 58 (48 WOOD FLOAT, 10 STEEL TROWEL)
- H2 S2 ASPHALT - 50 (26 HWY, 24 SEALED)
- 3 PLATE STEEL - 20
- 4 ALUMINUM
- 5 GALVANIZED ROOFING - 20
- 6 TAR PAPER ROOFING - 20
- 7 WOOD, UNPAINTED - 20
- 8 GLASS - 20
- 9 BRICK - 20
- 10 STUCCO - 20
- 11 SHINGLE - 18
- 12 WOOD, PAINTED - 18
- G GRASS, RYE - 20
- WC SC 10' x 10' CONCRETE - 17 (9 WOOD FLOAT, 8 STEEL TROWEL)
- HA SA 10' x 10' ASPHALT - 17 (9 HWY, 8 SEALED)
- WC 24' x 50' CONCRETE (WOOD FLOAT)
- 24' x 50' ASPHALT (HWY, FINISH)
- S 35' x 100' CLEARED SURFACE (EXPOSED SOIL)

Fig. 2.1 -- Pad array.

Fig. 2.2 -- Asphalt pad, 24 by 50 feet.

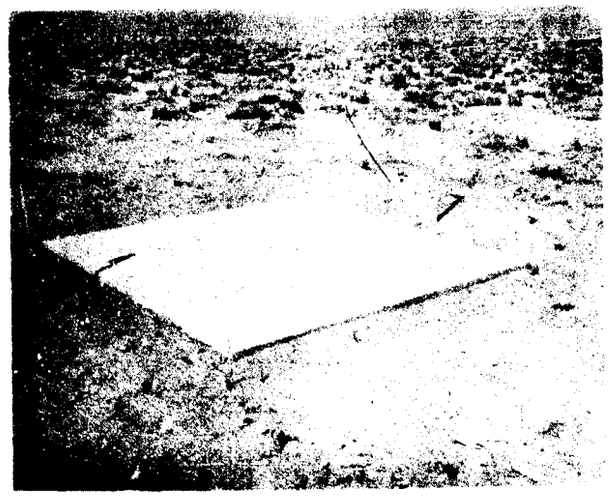


Fig. 2.3 -- Concrete pad, 10 by 10 feet.

Fig. 2.4 -- Unpainted wood pad, 2 by 2 feet.

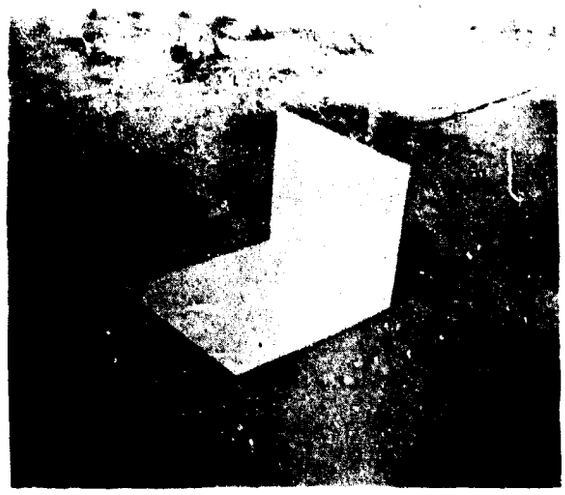


Fig. 2.5 -- Asbestos shingle pad, 2 by 2 feet.

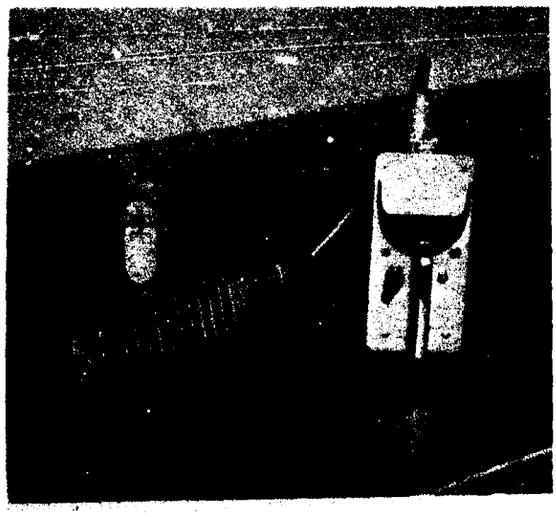


Fig. 2.6
Eberline gas flow survey instrument.

A second type of gas flow proportional counter was used in the laboratory for counting alpha concentration on air samples. The counting chamber, built by the Los Alamos Scientific Laboratory, is a large unit capable of handling samples as large as 3-1/2 by 8 inches. The probe is connected to a LASL P1-2 count-rate meter, the output of which is counted by a Nuclear Chicago Ultra Scaler, Model 192 (Fig. 2.7). This unit was also calibrated by use of the large-area distributed sources described above.

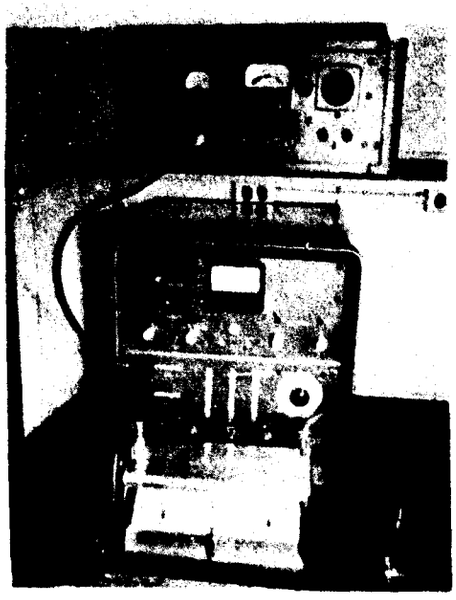


Fig. 2.7
Laboratory gas flow proportional counter.

2.2.2 Air Samplers

Air samples were taken by a variety of units. High-volume samples were collected at a rate of approximately 50 cubic feet per minute by the Staplex air sampler, Type TF1A, with modified head (Fig. 2.8). The head accommodates 8- by 10-inch glass-fiber filter paper, Type 1106-B, manufactured by Mine Safety Appliances Company, Pittsburgh, Pennsylvania. It is rated as 99.98-percent efficient for 0.3-micron particles.

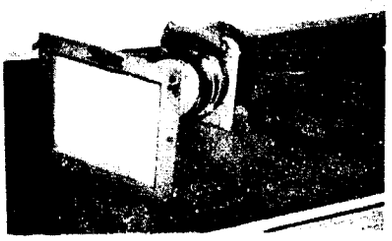


Fig. 2.8 -- Staplex air sampler with adapter head.

Low-volume samplers (10 liters per minute) with 47-millimeter-diameter Millipore filters were used. These units have the capability of removing particle sizes of 0.2 micron or greater (Fig. 2.9).

Fig. 2.9 -- Millipore air sampler with 47-mm head.

Four- and seven-stage impactors were used to obtain particle size distribution. All air samplers were calibrated as to flow by use of either a wet test meter or an Alnor velometer.

All air samples were counted in the laboratory and shipped to a contractor for chemical analysis. Laboratory counting was done 72 hours after collection to allow the naturally occurring alpha emitters to decay. A discussion of necessary time delay for counting air samples is found in Appendix B.

This instrumentation was supplemented by placing microscope slides (Fig. 2.10) in the area at selected points during cloud passage. Optical and electron microscopy were used to evaluate these slides as to size of particulate.

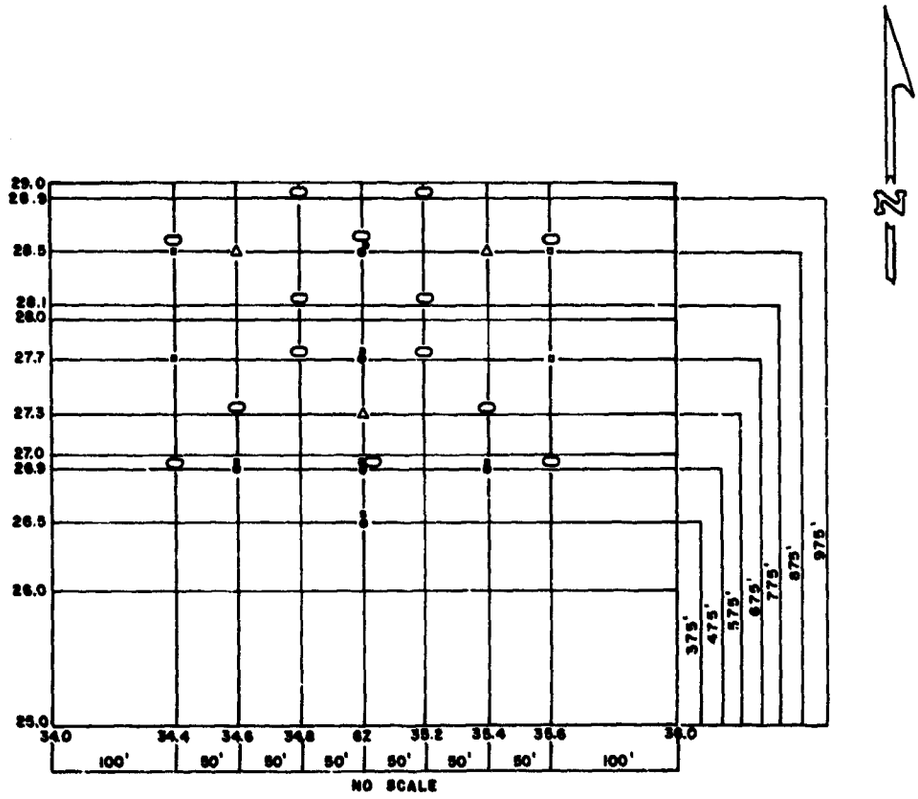


Fig. 2.10 -- Plot of air sampler array.

2.2.3 Soil Sampling

Vertical soil sampling was accomplished by pressing a 1-foot-square, thin-walled metal frame into the ground. One 1/4-inch, two 1/2-inch, and two 1-inch layers of soil were then successively removed from within the frame, beginning at the top and progressing downward to a depth of 3-1/4 inches. In addition, surface soil samples in units of 1 square foot of 1/2-inch depth were taken.*

2.2.4 Decontamination Equipment

Decontamination equipment included a single-bottom farm plow (Fig. 2.11), a disk harrow (Fig. 2.12), a 1000-gallon water-sprinkling truck, an 850-gallon oil-distribution truck (Fig. 2.13), two 400-gallon Air Force decontamination trucks (Fig. 2.14), two "Tornado" vacuum cleaners (Fig. 2.15), a "steam jenny," and a sand blaster.

*Other soil sampling by a different technique was performed by Program 71.[8]

Fig. 2.11 -- Single-bottom farm plow.

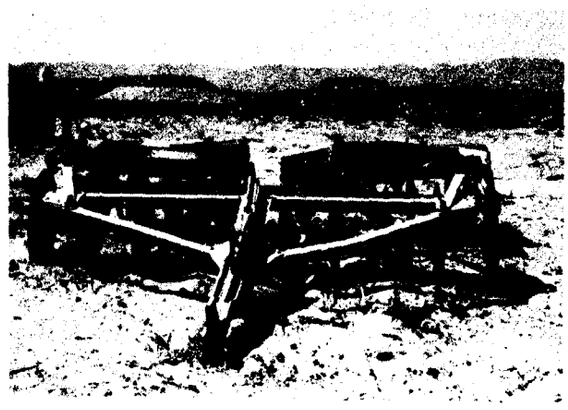


Fig. 2.12 -- Four-gang disk.

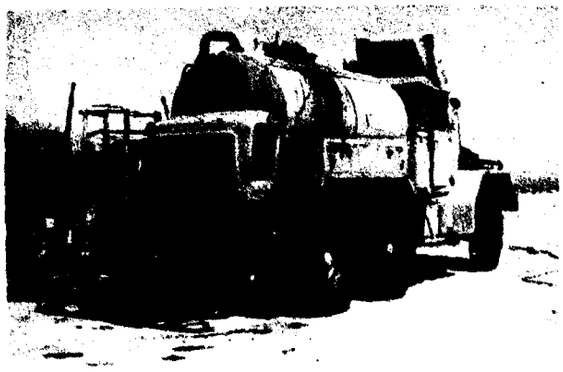


Fig. 2.13 -- USAF oil-distribution truck.

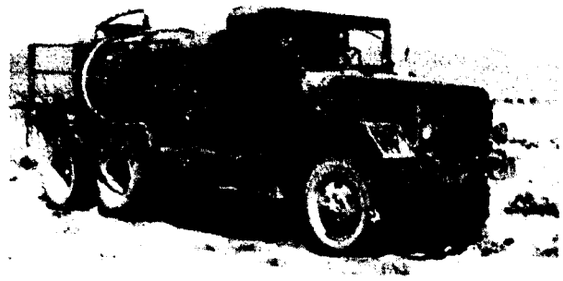


Fig. 2.14 -- USAF decontamination truck.

Fig. 2.15 -- Tornado vacuum cleaner.

2.3 FIELD OPERATION

To document the contaminating event and evaluate effectiveness of decontamination procedures, extensive surface and air monitoring were carried out and soil samples were taken. Wind direction and velocity at 6 feet above ground were recorded by two self-recording anemometers.

2.3.1 Preshot Preparation

Construction and placement of the pad array were completed several weeks prior to shot day. A few hours before H-hour, 23 air samplers, 25 "sticky pans," and 75 microscope slides (Fig. 2.10) were readied at selected points to record airborne plutonium concentration and to determine quantities of fallout. At H-40 minutes, air samplers located 375 to 975 feet north of ground zero were energized. The "sticky pans," 9-inch squares of sheet metal coated with a slow-drying resin, were located from a few hundred feet south to 3000 feet north of ground zero. These were furnished by Program 71 and placed by Program 74. Microscope slides, coated with Formvar, were mounted in sets of three, each set consisting of one horizontally and one vertically mounted slide, together with a third mounted at a 45-degree angle. One set was located at each of ten stations in Area B, ten stations in Area C, and five stations in Area D (see Fig. 2.16).

2.3.2 Postshot General Operation

The contaminated area was entered first at H+2 hours in order to recycle air samples, to begin surface monitoring, and to perform soil sampling. Operations for D-day and D+1 consisted of documentation of contamination levels within the Program 73 array. Beginning with D+2, decontamination methods were tested through D+31.

2.3.3 Surface Monitoring

The total pad array and selected soil stations were monitored on D-day and D+1. Beginning at D+3 and continuing through D+26, a group of representative pad and soil stations were monitored at selected intervals with a gas flow proportional alpha counter (Fig. 2.6).

2.3.4 Air Sampling

From H-40 minutes to H+2 hours, Staplex air samplers, Millipore filters, cascade impactors, annular impactors, and a Battelle impactor were in operation to document cloud passage. At H+2, all samplers and impactors were cycled and collection of microscope slides and fallout trays was begun. From H+2 to D+2, all air samplers were run continuously and were cycled at selected intervals. Impactors were operated throughout this period during daylight hours. Two Staplex air samplers, located approximately 500 feet north of ground zero, were operated

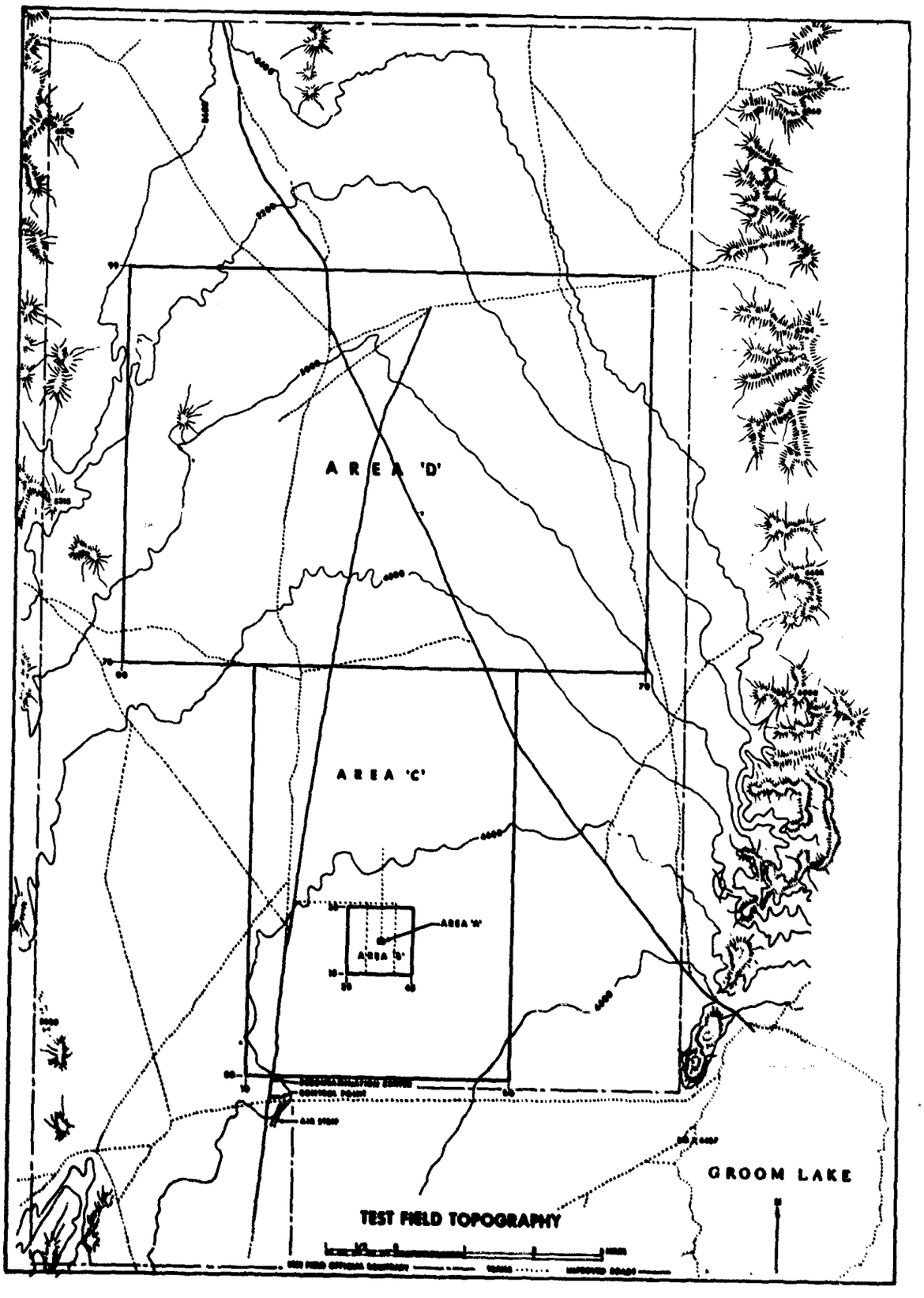


Fig. 2.16 -- Layout and general topography of test field.

continuously and cycled when feasible, usually every 24 hours, for a period extending from D+2 to D+33. Continuous wind direction and velocity and periodic accumulated rainfall measurements were made in an attempt to correlate air concentrations with meteorological conditions.

2.3.5 Soil Sampling

On D-day and D+1, approximately 100 surface soil samples, 1 foot square by 1 inch deep, were taken throughout the pad array to document the absolute plutonium contamination levels. Five grass samples in 2- by 2-foot flats were also collected.

2.3.6 Decontamination of Pad Array

On D+3, decontamination of pad surfaces was begun. Pad decontamination was accomplished as follows: For each decontamination procedure, a series of pads consisting of several types of hard-surface and building material was selected, monitored, decontaminated, and remonitored. Methods tested include vacuuming, water hosing, water scrubbing, water-detergent hosing, water-detergent scrubbing, steam cleaning, and sandblasting.

Vacuuming. Two Tornado industrial vacuum cleaners were modified to accept an MSA Ultra-Aire Space Filter in lieu of the conventional vacuum bag to preclude resuspension of contamination (Fig. 2.15). Relative measurement of the inlet air flow indicated that there was negligible reduction in air velocity as a result of this modification. After initial monitoring, a visual indicator (i.e., floor-sweeping compound) was spread on horizontal surfaces, insuring that the total area was covered by the vacuuming process. A bristle brush head and a rubber squeegee head were evaluated.

Water Methods. A standard Air Force decontamination truck was utilized to apply water decontamination methods. This unit consists of a 400-gallon water storage tank, high-pressure pump, and hose, all mounted on a standard 6-by-6 truck bed (Fig. 2.14). Water pressure attainable varied between 400 to 750 pounds per square inch. All surfaces to be decontaminated were initially covered with a visual indicator as previously described. With the water-hose method, the visual indicator was cleaned from the surface and the material moved from one side to the other. The surface was then permitted to dry prior to monitoring. The water-scrub method was similar with the exception that the surface was scrubbed with commercial long-handled scrub brushes after hosing and then flushed with clean water. Water-detergent-hose and water-detergent-scrub techniques are the same as described above with the addition of 1 percent by weight of Alconox detergent. In all cases the solution was removed from the surface by hosing with clear water.

Sandblasting. A standard sandblasting unit was mounted on a power wagon for use in the field. After initial monitoring, pads were sandblasted. Change in appearance of the surface was used as a guide in determining treated areas. During

this operation, the hose was held from 1 to 2 feet from the surface. Because of the size of the pads, there was no need for further removal of sand and loose contamination, since the stream of air and sand was sufficient to blow all loose material away.

Steam Cleaning. A standard Air Force vapor cleaner was mounted on a trailer for field use, with water and electricity furnished by mobile units. Outlet pressure, entirely steam, was approximately 90 pounds per square inch. By the time steam cleaning was started, some dust had accumulated on the pads and served as a visual indicator

2.3.7 Decontamination of 24- by 50-Foot Pads

Prior to decontamination, contaminant on the surface was artificially resuspended in the air while air samplers were operated. Resuspension was accomplished by four men who agitated the surface with straight brooms in a circular motion to preclude any great horizontal movement of contamination. (Several other methods of resuspension had been proposed, but it was determined that this method was best in this situation.) Two Staplex samplers and one Millipore sampler were mounted on a centerline running the length of the pad. A similar arrangement was set up along the 50-foot edge on the downwind side of the pad. One Casella cascade impactor was mounted approximately 25 feet downwind from this array. All air samplers were located 5 feet above ground. The resuspension period lasted for approximately 7 minutes, with all air samplers running an additional 8 minutes. Settling, after resuspension, took place in as nearly a no-wind environment as possible (less than 5 knots).

After resuspension, the areas were decontaminated by water-detergent hosing as previously described. A second resuspension, in the same manner, gave a measure of decontamination efficiency.

2.3.8 Decontamination of Land Areas

Eleven 50- by 100-foot soil areas were selected within the pad array (Fig. 2.17). Each area was monitored at six locations and vertical soil samples were taken at two locations. Four Staplex and two Millipore samplers were set up within each area, with a cascade impactor located 30 feet downwind from the area. Each surface was then artificially resuspended in less than a 5-knot ambient wind condition by repeatedly driving a truck back and forth through the area. Resuspension took approximately 7 minutes, and air samplers were operated for a total period of 15 minutes. The area was then monitored and decontaminated by the method selected for the particular area. Each area was monitored again and, where applicable, vertical soil samples were taken. The area was subjected to resuspension for the second time in the same manner. Methods of earth decontamination or fixation included oiling, spraying with fire-fighting foam, wetting, flooding, wetting with leaching agents, disking, plowing, and scraping.

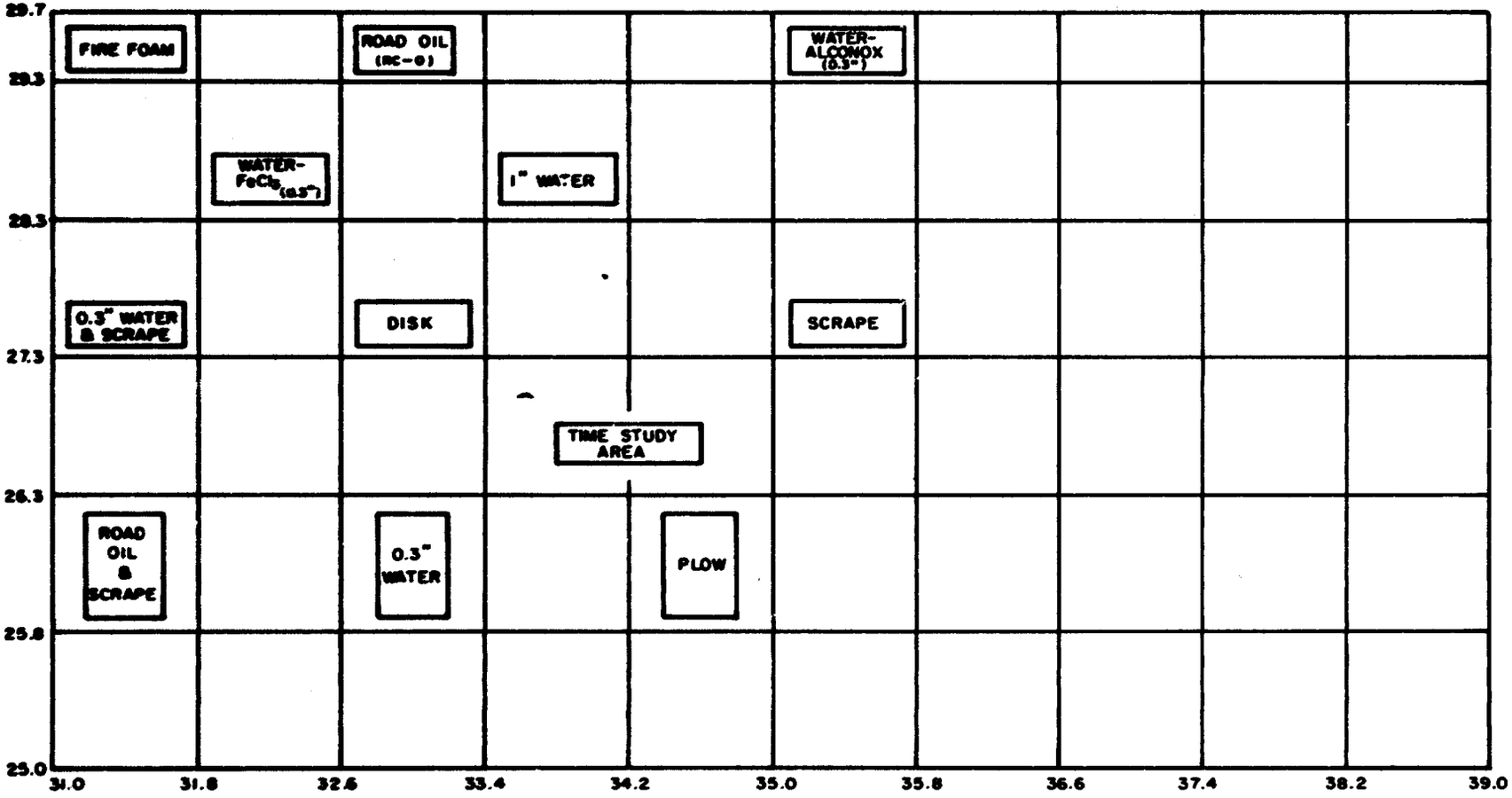


Fig. 2.17 -- Plot of land decontamination areas.

Water Leaching Methods. A USAF water-distribution truck was used in decontaminating five areas. Two areas were covered with 0.3 inch of water and another flooded with 1.0 inch of water, to simulate, respectively, moderate and heavy rainfall during a period of an hour. The effect of leaching agents was tested by adding 1 percent, by weight, of Alconox detergent and ferric chloride, respectively, to water and covering each of the areas to a 0.3-inch level.

Earth Mixing Methods. A conventional single-bottom farm plow and a four-gang disk were used (Figs. 2.11 and 2.12); one area was disked to a 4-inch depth, and a second was plowed to a 12-inch depth.

Earth Fixation Methods. Two areas were oiled with Type RC-0 road oil to a depth of 0.15 inch by a USAF oil-distribution truck (Fig. 2.13). This type of oil was chosen for its ability to penetrate the surface and set up in a minimum amount of time. As a temporary fixing agent, USAF Type 5 Charge fire-fighting foam was mixed in a decontamination truck and sprayed over the area with a foam nozzle.

Earth Removal. The top 2 to 4 inches of soil were removed from three areas with a U.S. Army roadgrader. The first area had been previously oiled, the second wet with 0.3 inch of water, and the third had been undisturbed.

2.4 THREE- AND SIX-MONTH STUDIES

At 3 and 6 months postshot, trips were made to the Nevada Test Site to study effects of weathering on plutonium contamination. Twenty-four hour quiescent air samples were taken for about 4 days on each trip. On each trip, an area adjacent to an area resuspended during the first month was resuspended to observe the decline in resuspension factor with time. These areas are in the Time Study Area shown in Fig. 2.17.

Numerous soil samples were taken within the pad array and on the North Line to study migration of plutonium into new areas and its penetration into soil. One area was resuspended three times to observe the decrease in resuspension factor. Air samples were taken during actual resuspension and during interim periods.

2.5 TWELVE- AND EIGHTEEN-MONTH STUDIES

On 12- and 18-month postshot trips to the Nevada Test Site, data and samples were taken to further document weathering effects on plutonium contaminant. Quiescent and resuspension air samples were taken. Soil samples were taken to document contamination levels and to determine depth of penetration.

Chapter 3

RESULTS AND DISCUSSION

3.1 SOIL SAMPLING

Numerous soil samples taken on D-day and D+1 were used primarily to correlate alpha survey meter readings with actual soil contamination levels. This is discussed more fully in Section 3.2.1.*

Depth profile soil samples, even a year and a half after D-day, show that greater than 95 percent of the plutonium is contained in the upper quarter inch. This is to be expected because of the small amount of rainfall experienced in the area and the fact that although plutonium oxides are all but insoluble, some fixing action seems to occur.

Soil samples taken in the same vicinity over a period of 18 months indicate that within the probable error of each determination there has been no migration of plutonium from the site of original deposition.

Plutonium concentration on five grass pads collected on D-day and adjacent soil samples are shown in Fig. 3.1. As can be readily observed, "grass numbers" are consistently higher than those of adjacent soils. This results from the trapping of pl[illegible]onium by leaves of grass. Thus, grass tends to catch more plutonium than adjacent bare soil, holding it more tenaciously and preventing it from being resuspended.

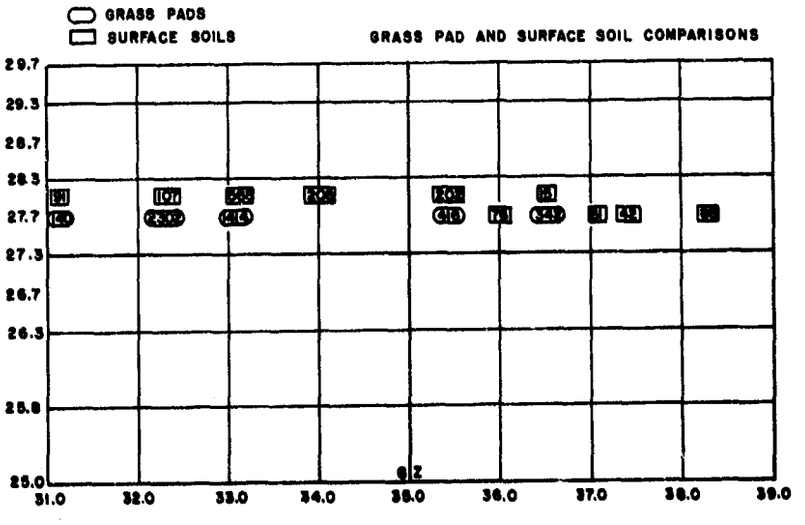


Fig. 3.1 -- Grass pad and soil contamination comparison.

*See WT-1510[8] in which additional soil sampling at these and much greater distances from ground zero are reported.

3.2 SURVEY MONITORING

Survey monitoring on D-day gave a thorough documentation of plutonium contamination levels within the pad array. Survey monitoring on later days resulted in factors for meter indications of virtual alpha activity degradations with time.

3.2.1 Contamination Levels as Determined by Survey Monitoring

Extensive surface alpha survey monitoring was conducted throughout the pad array on D-day. Initial count rates, as determined by the Eberline gas flow counter, ranged from 15,000 counts per minute (cpm) to greater than 100,000 cpm on horizontal surfaces (soil and pads). By comparison, pads placed in the vertical position were, in general, less contaminated by a factor of 100 or more than were the horizontal surfaces.

At 36 points in the array, a surface was monitored and an adjacent soil sample was taken. The $\mu gm/m^2$ as determined chemically from the soil sample were compared with cpm as determined by the alpha survey meter. As noted from Table 3.1, the average of this ratio is 330 cpm per $\mu gm/m^2$. This ratio is an average for all types of surfaces and is valid only on D-days. On later days effects of weathering must be considered.

Contours in Fig. 3.2 were drawn from the measured average ratio of 330 cpm per $\mu gm/m^2$ and Program 73 monitoring data from D-day. Outside the pad array, monitoring data from Program 74 were used. From Fig. 3.2, areas within the contours were determined and are presented in Table 3.2. Comparative areas determined by Program 74 with the conversion ratio 250 cpm per $\mu gm/m^2$ are shown also; because of better statistics, Program 74 results are favored.

3.2.2 Surface Monitoring as a Function of Time After Shot

Surface alpha monitoring was conducted at selected points throughout the pad array from D-day to D+26, with additional readings at 3, 6, 12, and 18 months post-shot. Repeated surveys indicated a decrease in surface reading with time, magnitude of decrease being a function of porosity of the surface involved. For purposes of comparison, surfaces were separated into three classifications: smooth, rough or porous, and soil. Smooth surfaces consisted of glass, plate steel, aluminum, and painted wood. Rough or porous surfaces were unpainted wood, tarpaper, sealed asphalt, stucco, and wood shingle. Plots of normalized representative surface readings versus time are shown in Fig. 3.3. It was observed that meter readings on smooth surf ces decreased by a factor of 10 by D+7 and 100 by D+30. Meter readings on rough surfaces decreased by a factor of 2.5 by D+7 and 6.6 by D+30. Soil meter readings decreased by a factor of 15 by D+7 and 40 by D+30. Plots of degradation factors versus time are shown in Fig. 3.4.* It should be remembered

*See also separate determinations in WT-1513.[9]

that reduction in meter readings is the result of weathering, i.e., rain, wind, dust films, etc., and is not a true nuclear decay, since plutonium has a 24,000-year half-life. Surface monitoring data is presented in Appendix C.

TABLE 3.1 -- MONITORING, CHEMICAL COMPARISON

Location (Station)	Monitoring (cpm)	Chemical ($\mu gm/m^2$)	Ratio (cpm/$\mu gm/m^2$)
26.7-31.8	75,000	180.1	416
27.3-33.6	48,000	99.2	483
27.3-33.6	64,000	99.2	645
27.5-35.0	27,000	72.1	374
27.7-36.6	32,000	61.3	552
27.5-35.0	27,000	122.0	221
28.7-34.6	15,000	74.2	202
28.7-33.0	33,000	194.8	169
28.3-35.0	22,000	51.2	429
29.3-33.4	35,000	159.2	220
29.3-31.0	15,000	103.5	145
29.3-35.0	35,000	253.9	138
29.7-31.6	35,000	115.8	302
29.7-34.2	32,000	41.4	772
29.3-35.8	33,000	65.2	506
25.8-36.6	50,000	360.2	139
25.8-37.4	65,000	276.0	236
26.7-39.0	45,000	85.5	526
26.3-36.6	96,000	261.5	367
27.3-33.4	90,000	778.0	116
27.3-35.0	45,000	97.0	463
27.3-36.6	48,000	204.0	235
27.3-37.4	28,000	173.7	161
27.7-32.2	10,000	107.2	93
28.3-35.0	34,200	105.8	323
28.7-33.8	10,000	88.0	113
29.3-35.0	35,000	277.6	116
29.3-34.2	40,000	91.6	436
29.7-31.0	85,000	364.0	234
29.7-32.8	78,000	326.0	239
29.7-34.8	38,000	90.5	419
29.3-31.8	47,600	54.3	877
29.3-33.4	65,000	505.0	129
29.3-35.0	35,000	56.0	625
29.3-36.6	20,000	56.5	353
29.3-31.0	15,000	110.1	136
		Average	330
		Median*	270

*Midpoint of central values. Note that median conversion factor agrees reasonably with 250 cpm/$\mu gm/m^2$ arrived at by Program 74 from many more data[9] on brush-finished concrete surfaces only.

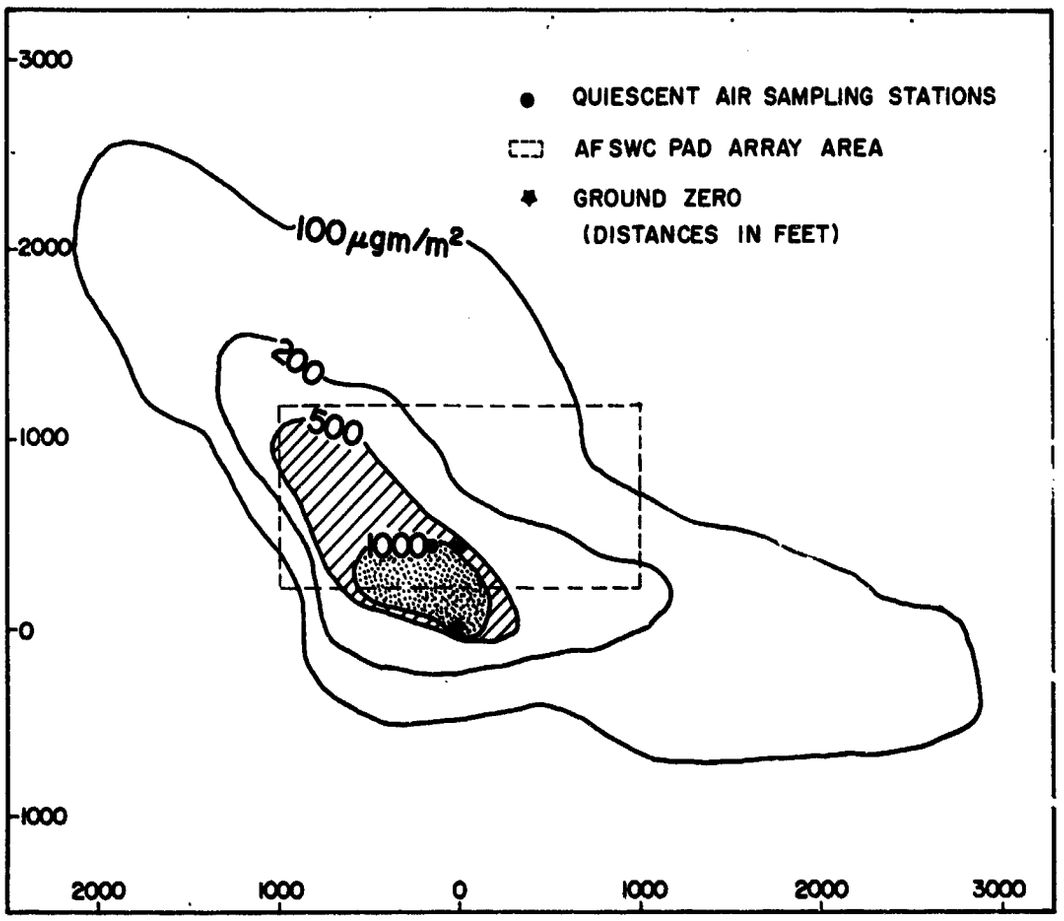


Fig. 3.2 -- Contours of contamination.

TABLE 3.2 -- AREAS OF CONTAMINATION

Area Contamination Level ($\mu gm/m^2$)	Area Contaminated (sq. mi.)	
	Program 73	Program 74
1000	0.009	0.03
500	0.030	0.07
200	0.076	0.15
100	0.27	0.43

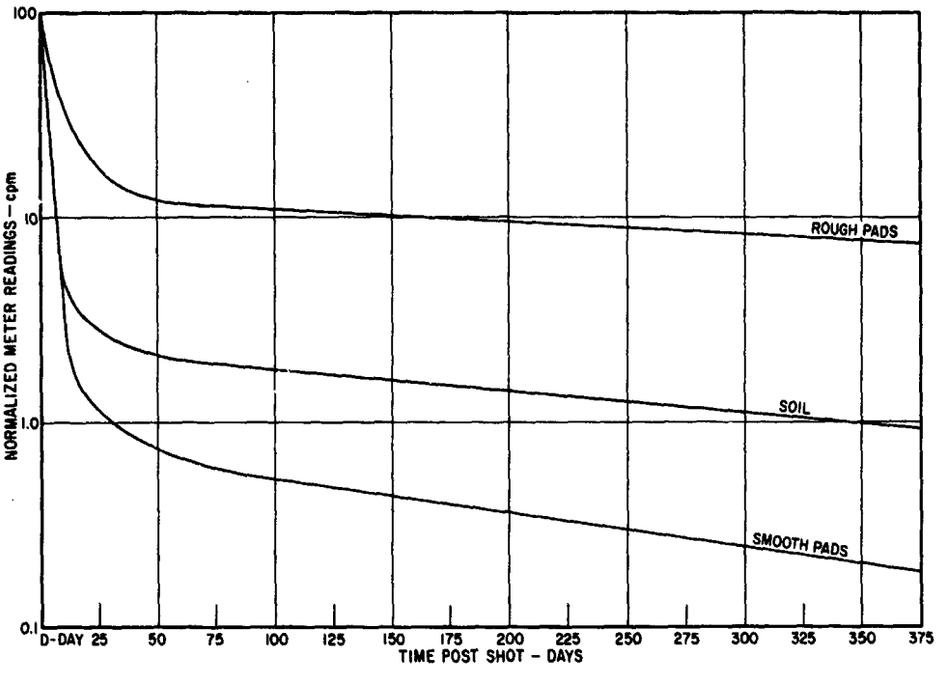


Fig. 3.3 -- Normalized meter readings as a function of time.

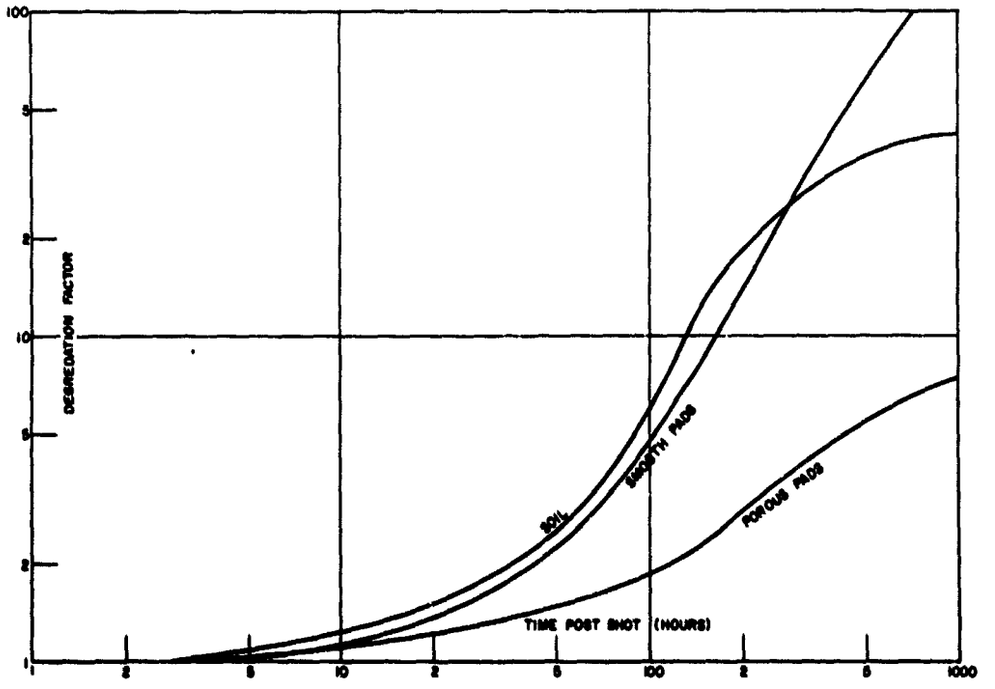


Fig. 3.4 -- Surface monitoring degradation factors as a function of time.

3.3 AIR SAMPLING

3.3.1 Air Sampling as a Function of Time After Shot

Air samples collected within the pad array during the time interval from H-hour to H+3 gave an average air concentration of 30,000 disintegrations per minute per cubic meter (dpm/m^3). Lowest concentration was 8600 dpm/m^3 at Station 28.9 - 34.8; highest was 75,000 dpm/m^3 at Station 27.7 - 34.8. Table 3.3 shows air concentration at nine points within the pad array during cloud/passage.*

TABLE 3.3 -- CLOUD PASSAGE AIR CONCENTRATION

Location (station)	Air concentration (10^3 dpm/m^3)
26.9-35.0	27.0
26.9-35.6	9.3
27.3-35.4	14.0
27.3-34.6	17.0
27.7-34.8	75.0
27.7-35.2	41.0
28.1-35.2	59.0
28.9-35.2	16.0
28.9-34.8	8.6

Succeeding air samples of approximately 3- and 24-hour intervals showed a very rapid decrease in air concentration in the quiescent condition. There was a decrease by as much as a factor of 100 by H+7, with concentration reaching a fairly steady state of around 4 dpm/m^3 by D+15. During this period extreme fluctuation was observed, changing by a factor of 100 in a 2-day interval. Maximum concentrations were associated with periods of high winds, while minimum concentrations were associated with rainfall and low winds. This relationship can be observed by referring to Figs. 3.5 through 3.8.

Figures 3.5 and 3.6 show air concentration as a function of time after shot for two stations located approximately 500 feet north of ground zero. Figure 3.7 is a plot of wind velocity versus time, and Fig. 3.8 presents rainfall data.

At 180 days postshot, quiescent air concentration was 0.63 dpm/m^3. At 1-year, average concentration was 1.2 dpm/m^3, and at 18 months it was 0.4 dpm/m^3.†

*See also WT-1510[8] for similar measurements at these and greater distances from ground zero.

†All of these measurements were within the Program 73 array and were a function of wind vector during the short period of observation. Thus, the data are roughly indicative only.

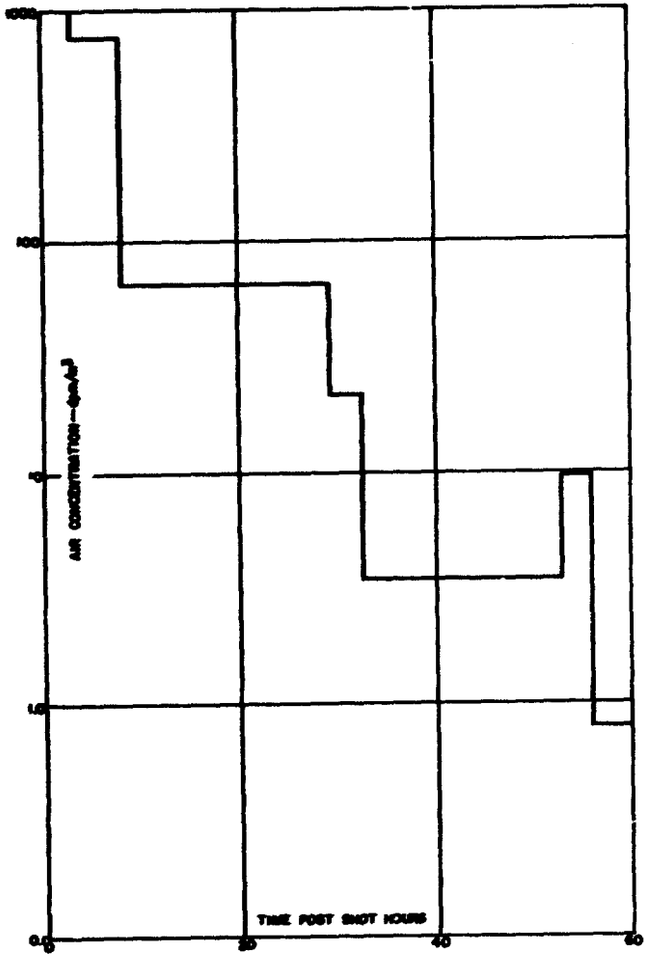


Fig. 3.5 -- Air concentration as a function of time, Station 26.9 - 34.4.

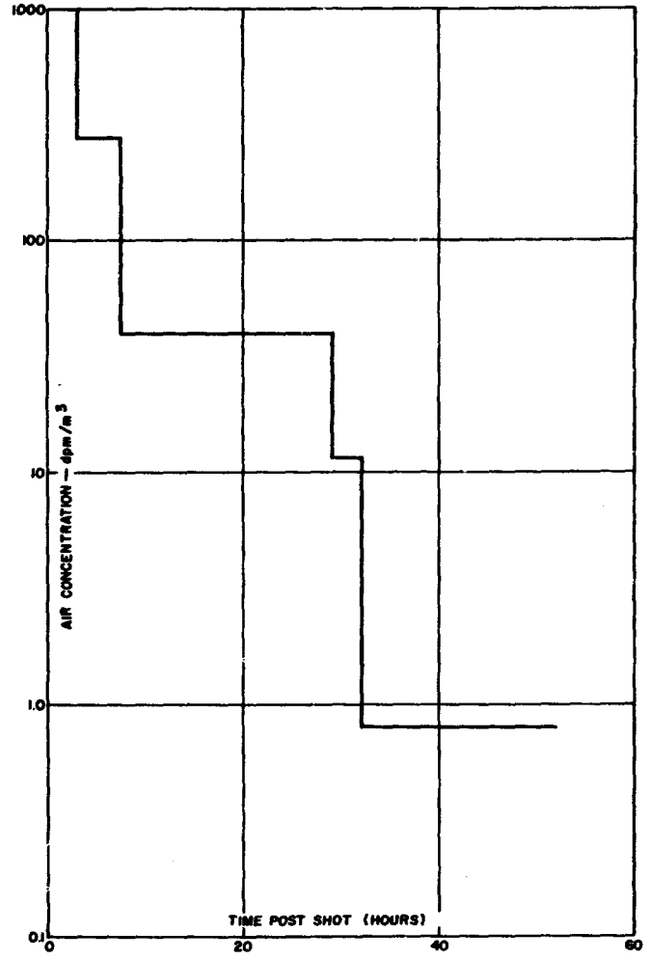


Fig. 3.6 -- Air concentration as a function of time, Station 27.7 - 34.8.

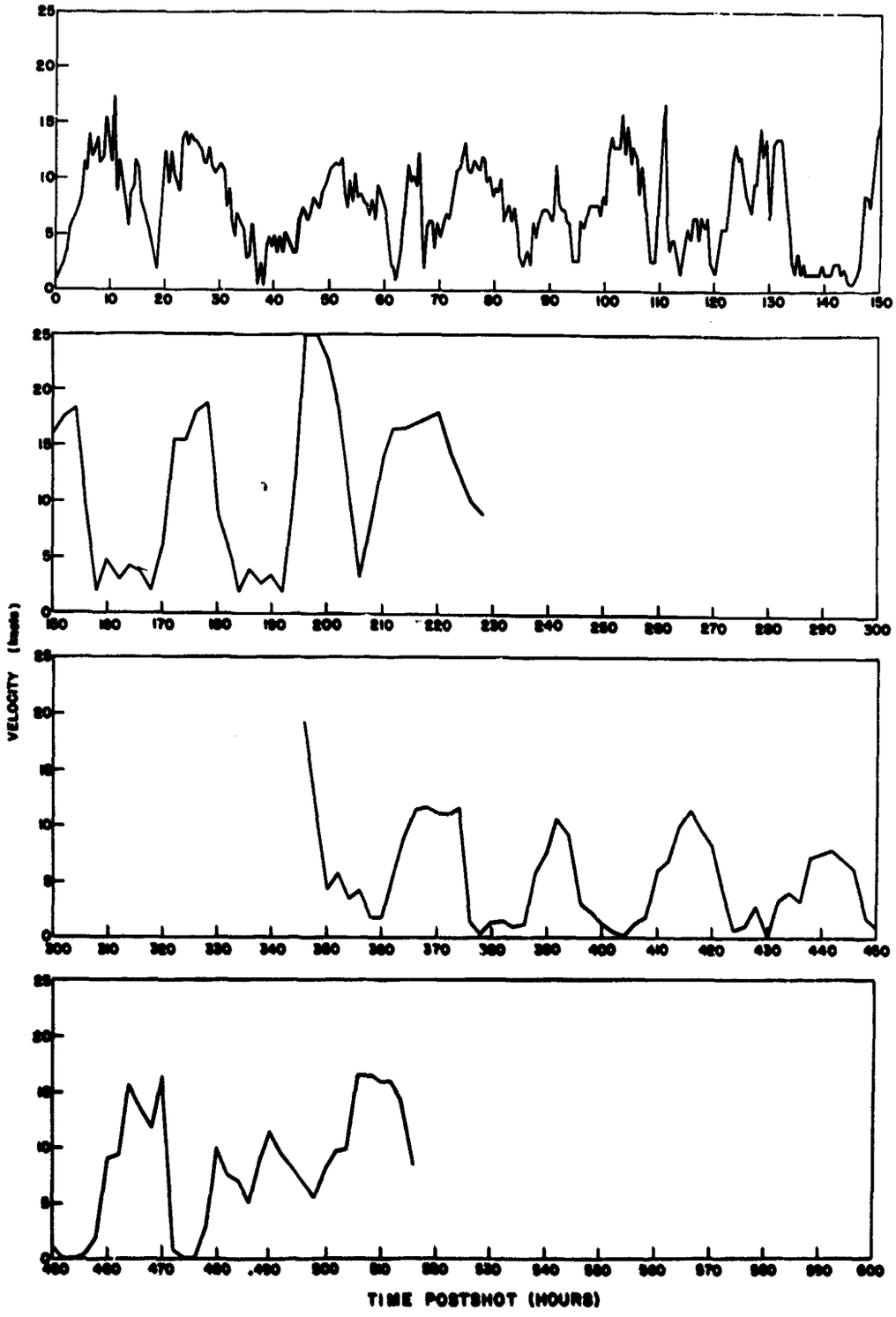


Fig. 3.7 -- Wind velocity versus time.

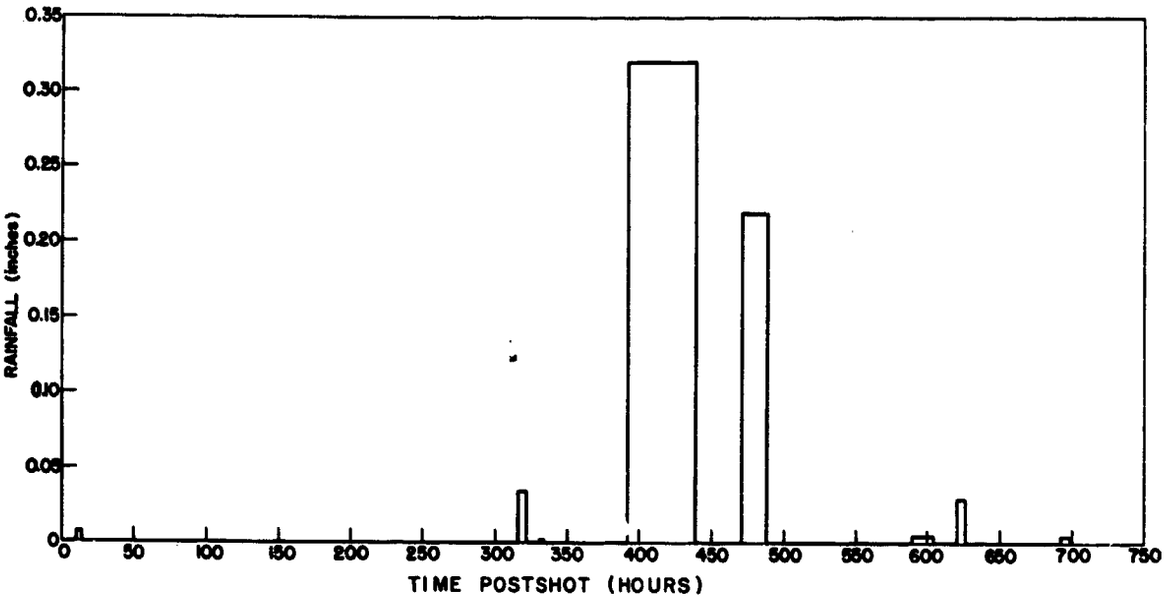


Fig. 3.8 -- Rainfall versus time.

3.3.2 Air Concentrations During Mechanical Resuspension

A resuspension factor is used in studying air concentrations during forced or mechanical resuspensions. The resuspension factor is the ratio of air concentration (dpm/m^3) to soil contamination level ($\mu gm/m^2$). A decrease of resuspension factors with time would be attributed to weathering of the contaminant. Resuspension factors are shown in Table 3.4. As can be readily seen, spread in resuspension factors precludes issuance of a definite statement relative to effects of weathering on the contaminant. This is due primarily to two elements. The first is that, while every effort possible was made to have resuspending activity identical in each resuspension, there was variation because of the nature of the Nevada desert. The amount of moisture in the ground varied, and wind velocity and direction varied, even during each resuspension. The second element precluding observation of a definite decrease in resuspension factor with time was that, even at 1-year postshot, all the plutonium was contained in the upper 1/2 inch of soil. The resuspending agent (a jeep with tires spinning) was quite able to pick up material at a depth of 1/2 inch and resuspend it into the air.

3.3.3 Air Concentrations Downwind from a Resuspension

To determine air concentration as a function of distance downwind from a resuspension activity, Staplex air samplers were located at 50-foot intervals downwind to a distance of 200 feet. At 50 feet downwind, activity was decreased by a

factor of three. At 150 feet, activity had decreased by a factor of 14. The indicated increase at 200 feet is in all probability caused by cross contamination of the sample. This information is presented in Fig. 3.9.

TABLE 3.4 -- RESUSPENSION FACTORS

Date 1957	Days postshot (D+)	Soil concentration ($\mu gm/m^2$)	Air* concentration (dpm/m^3)	Resuspension factor ($dpm/m^3/\mu gm/m^2$)
27 April	3	328	1,424	4.34
29 April	5	290	1,045	3.60
29 April	5	694	4,221	6.08
30 April	6	1346	8,127	6.07
30 April	6	98	221	2.26
6 May	12	276	1,405	5.09
7 May	13	260	515	1.98
8 May	14	156	206	1.32
8 May	14	312	500	1.60
10 May	16	73	79	1.08
17 May	23	442	2,630	5.95
15 May	21	478	2,019	4.22
22 July	88	737	1,224	1.66
22 October	180	709	944	1.33
1 Year	365	1870	3,770	2.02
1 Year	365	9560	30,800	3.22

*Approximately 5 feet above ground and adjacent to resuspension area.

3.4 PARTICLE SIZE

3.4.1 Cloud Passage

The three methods of particle size determination (fallout slides, Battelle impactor, and Casella impactor) used during cloud passage[1] gave essentially the same result; all particles were in the respirable range.* The average of 21 fallout slides between 500 and 1000 feet north of ground zero showed an average particle size of 0.75 micron, with 99 percent of the particles equal to or less than 2 microns. Forty-five slides from 2000 feet to 10 miles north of ground zero indicated an average particle diameter of 0.8 micron, with 99 percent of the particles equal to or less than 2.5 microns.

The five Casella impactors, 500 to 700 feet north of ground zero, had an average particle size of from 1 to 2 microns. A function of the Casella impactor is to separate particles into different size groupings on each stage. However, since all stages showed similar size distribution, either shattering resulted or cross contamination occurred during shipment.

*See also WT-1510.[8] Note that, for PuO_2 with density $P \approx 10$, effective diameters at unit density are $\sqrt{\rho}$ X, or approximately three times those given.

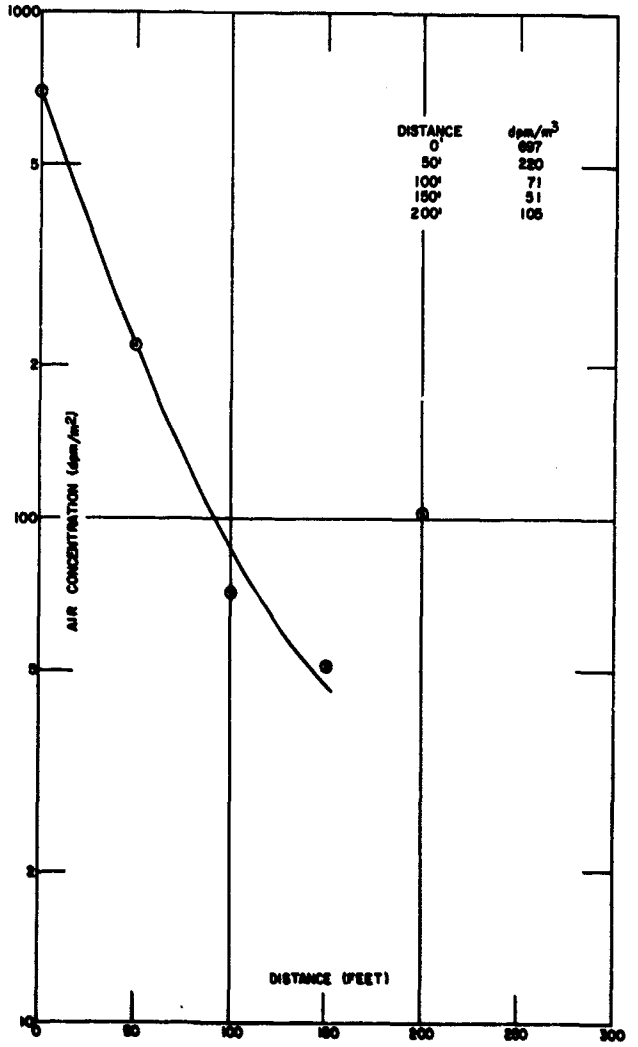


Fig. 3.9 -- Air concentration downwind from resuspension activity.

The Battelle impactor gave similarly poor particle size separation. Distribution is given in Table 3.5 with an average for all stages of 1.2 microns.

3.4.2 Particle Size During Resuspension

During resuspensions (D+3 to D+28) in land decontamination studies, a cascade impactor was in operation in the dust cloud. Particle size noted during these resuspensions was essentially the same as was observed during cloud passage. All were in the respirable range.

TABLE 3.5 -- CLOUD PASSAGE PARTICLE SIZE
(BATTELLE IMPACTOR)

Stage	Average particle size (microns)
1	1.3
2	1.6
3	1.4
4	1.4
5	1.2
6	0.7
Millipore	0.4

3.4.3 Particle Size at Later Times

At 1-year postshot, fallout slides and a Battelle impactor were exposed both under quiescent conditions and under active resuspension conditions. Mean particle diameter for each slide was determined. Results fall between 0.69 and 0.83 micron, with 99 percent of the particles having a diameter of less than or equal to 2 microns. Five examples are shown in Table 3.6. Thus, it is apparent that total plutonium air concentration must be considered as falling within the respirable range from cloud passage out to times of a year and longer after the shot.

TABLE 3.6 -- PARTICLE SIZE, ONE YEAR POSTSHOT

Boundary (microns)	Resuspension			Quiescent	
	(Freq. 1)	(Freq. 2)	(Freq. 3)	(Freq. 1)	(Freq. 2)
?-0.30	30	67	41	143	116
0.31-0.50	103	155	129	286	184
0.51-0.70	152	186	178	227	247
0.71-0.90	115	165	159	161	258
0.91-1.10	77	144	98	128	189
1.11-1.30	31	64	32	39	60
1.31-1.50	12	28	18	23	29
1.51-1.70	11	15	8	17	19
1.71-1.90	9	7	7	8	6
1.91-2.10	7	6	9	15	23
Mean particle diameter	0.75	0.75	0.73	0.66	0.74

3.5 DECONTAMINATION OF PAD ARRAY

3.5.1 Results for 2- by 2- and 10- by 10-Foot Pads

Results of pad decontamination are tabulated in Table 3.7 and summarized in Table 3.8. It was observed in general that effectiveness of decontamination was a function of cleaning technique rather than a function of the type of surface to which the technique was applied. For example, a method superior to other methods on one type of surface ranked equally well on other selected surfaces.

TABLE 3.7 -- HARD-SURFACE DECONTAMINATION EFFICIENCIES IN PERCENT

Material	Vacuum (D+2)	High-pressure water (D+3)	High-pressure water with scrub (D+12)	High-pressure water and detergent (D+4)	High-pressure water and detergent with scrub (D+5)	Sandblasting (D+9)	Steam cleaning (D+14)
Glass	98.95	98.85	97.79	100.00	99.76	100.00	97.86
Stucco	48.00	97.94	95.22	100.00	99.59	100.00	27.00
Painted wood	99.28	98.43	96.77	99.69	99.97	100.00	91.61
Unpainted wood	36.00	85.00	93.18	99.54	95.54	99.90	85.00
Aluminum	89.00	99.45	97.33	99.62	100.00	98.49	84.00
Plate steel	93.04	97.26	94.19	100.00	98.83	99.72	91.46
Asbestos shingles	61.00	99.97	98.91	96.89	99.36	100.00	63.00
Unpainted wood shingles	61.00	97.16	90.49	95.01	97.93	99.82	71.00
Brick	29.00	99.46	99.32	99.14	99.56	99.92	97.50
Tarpaper	55.00	98.66	95.04	95.32	96.83	99.51	52.00
Galvanized roofing	89.00	99.36	97.19	99.73	99.86	100.00	85.00
Highway asphalt	32.00	99.90	96.25	99.82	99.48	99.90	44.00
Highway asphalt (10 x 10 ft)	72.00	92.45	94.95	98.85	96.34	92.73	22.00
Sealed asphalt	71.00	98.67	90.00	100.00	99.72	99.61	84.00
Sealed asphalt (10 x 10 ft)	64.00	90.00	82.00	96.31	97.54	90.42	48.00
Steel trowel concrete	74.00	98.94	-----	96.91	99.53	100.00	-----
Steel trowel concrete (10 x 10 ft)	-----	78.00	97.34	------	98.58	98.96	27.00
Wood float concrete	-----	98.00	92.03	100.00	97.47	100.00	65.00
Wood float concrete (10 x 10 ft)	56.00	97.84	-----	98.09	98.28	98.78	85.00
Average of all surfaces	66.40	96.12	94.59	98.61	98.64	98.83	67.80

TABLE 3.8 -- EFFECTIVENESS OF VARIOUS DECONTAMINATION METHODS

Method	Effectiveness (percent)
Sandblasting	98.83
Water-detergent scrubbing	98.64
Water-detergent hosing	98.61
Water hosing	96.12
Water scrubbing	94.59
Steam cleaning	67.80
Vacuum	66.40

It will be noted that high-pressure water hosing has a better efficiency than that indicated for high-pressure water hosing with scrubbing action. However, this difference is probably due to the fact that high-pressure water hosing with scrubbing took place at D+12, permitting some time for weathering of the contamination, which subsequently decreased efficiency of this decontamination method.

Sandblasting, although ranked first in effectiveness, is not recommended for general use because of complexity of method, time involved in the operation, inherent damage to the surface being cleaned, and, perhaps most important, its creation of a dust cloud bearing plutonium-rich particulate. For general hard-surface decontamination, hosing with plain water or with a 1-percent-by-weight water-detergent solution provides the easiest and most economical means of decontamination. The slight increase in efficiency gained by addition of scrubbing action to either of the preceding methods is of questionable significance, and it is certainly not warranted in view of the increased expenditure of manpower. Steam cleaning is of use only where contamination adheres to greasy or oily surfaces such as those on vehicles. Vacuum cleaning is most useful on hard, smooth surfaces where use of water would be injurious (e.g., on electric motors and pumps). In all cases disposal of plutonium-rich cleansing agent must be carefully done.

3.5.2 Results for 24- by 50-Foot Pads

Large highway asphalt and wood-float concrete pads were decontaminated on D+23 by the water-detergent-hosing method. Hosing progressed along the length of the pad, and subsequent monitoring revealed no trend toward buildup of contamination at the far end of the pad. Effectiveness of decontamination as measured by air concentration is shown in Table 3.9.

Because of several rains which fell before decontamination, listed efficiencies are lower than would be expected with fresh contaminant.

TABLE 3.9 -- DECONTAMINATION OF 24- BY 50-FOOT PADS

	Average initial (dpm/m^3)	Average final (dpm/m^3)	Efficiency (percent)
Highway asphalt	44.6	31.2	30.0
Wood float concrete	56.4	13.2	76.6

3.6 DECONTAMINATION OR FIXATION OF LAND AREAS

3.6.1 Temporary Measures

Air Force fire-fighting foam worked well as a temporary fixing agent, but its usefulness was exhausted within an hour. High desert temperature and dry wind produced rapid evaporation and disappearance of the foam. During the period of the foam's usefulness, air concentrations produced by resuspension were reduced from 1424 to 154 dpm/m^3 for a 90-percent efficiency.

3.6.2 Permanent Measures

Efficiencies of various land fixation or decontamination methods are indicated in Table 3.10.

Both plowing and scraping are effective methods of removing contamination from the surface, and the recommended choice of method will depend on availability of equipment. Leaching contamination into the soil with water or a ferric chloride solution is another alternative which appears to be effective and useful. Disking is not as efficient as plowing, since much of the contamination remains on the surface, whereas plowing tends to turn the contaminant under the furrow. Burial action in plowing can be enhanced by first wetting the surface to keep surface dust from rising into the air and settling back on an adjacent clean furrow. There appears to be an inconsistency in comparison of effects of leaching with 0.3 inch of water and leaching with water-Alconox solution. The latter should be at least as effective as a leaching agent as plain water. Its lesser effect is due probably to its use on a plot of ground which had previously been scraped and weathered for a month, thus forming a tough top layer which, in turn, hindered penetration of the solution into the soil.

TABLE 3.10 -- PERMANENT LAND DECONTAMINATION EFFICIENCIES

Method	Mean initial (dpm/m^3)	Mean final (dpm/m^3)	Efficiency (percent)
Plowing	2630	55	97.9
Oiling and scraping	1240	55	95.6
0.3-inch water leaching and scraping	205	15	92.7
0.3-inch water $FeCl_3$ leaching	1405	118	91.6
Disking	500	54	89.2
1.0-inch water leaching	515	65	87.4
Scraping	79	11	86.0
Oiling (RC-0 road oil)	121	37	69.4
0.3-inch water leaching	8133	3660	55.0
0.3-inch water-Alconox leaching	380	309	18.7

3.7 DECONTAMINATION OF EQUIPMENT

3.7.1 Vehicles

All vehicles used in the contaminated area were decontaminated to below AEC acceptable levels. One thorough hosing with water was sufficient to decontaminate most vehicles. The only vehicle which presented a problem was the road-oil distribution truck on which plutonium was imbedded in spots of oil. Although this contamination presented no hazard in its fixed position, considerable time and effort were expended to remove it by scrubbing and scraping. It is recommended that vehicle decontamination include cleansing of the engine air cleaners, since they tend to accumulate a sizable amount of contaminant.

3.7.2 Test Equipment

Miscellaneous pieces of equipment, air samplers, survey instruments, wind-measuring equipment, etc., were readily decontaminated by washing with soap and water or by vacuuming.

3.8 RADIOLOGICAL SITUATION

Potential radiological danger from a nonnuclear detonation of a plutonium-bearing weapon results from inhalation of plutonium oxide or plutonium metal particles within respirable particle size range. Other modes of entry into the body can be considered as insignificant.[2] The inhalation study is best discussed in two phases: acute (cloud passage) and chronic exposure.

3.8.1 Cloud Passage

In connection with the acute case during cloud passage, it was noted that the average air concentration from 11 air samplers was 30,000 dpm/m^3, with the highest measured concentration of 75,000 dpm/m^3 at 675 feet north of ground zero. At this station, air sample filter paper contained 110 μgm of plutonium. This sampler operated at 1740 liters per minute, compared with a normal adult breathing rate of about 20 liters per minute during work or outdoor activity. Thus, the maximum quantity that would have been breathed into a human lung during cloud passage would be about 1.26 μgm, or 0.077 microcurie (μc). For inhaled insoluble plutonium, bone and lung are the only critical organs. Since approximately only 10 percent of the inhaled dose is absorbed into the blood stream and ultimately deposited in bone, the systematic burden from such an exposure would be only 19 percent of the maximum permissible level for bone of 0.04 μc. Since the bone level is so low, 19 percent of mpl, exposure to the lung is the only possible source of concern. From the Los Alamos lung model,[3] it has been determined that 25 percent of inhaled plutonium is exhaled immediately without deposition on lung or bronchial surfaces. This leaves the amount deposited 0.058 μc, approximately three times the permissible lung burden of 0.02 μc. The Los Alamos lung model gives three compartments for removal of insoluble particulate matter. Fifty percent of the inhaled amount is removed with a half-time of 20 days, 15 percent is removed with a half-time of 180 days, and 10 percent is removed with a half-time of 1 day; the other 25 percent is exhaled immediately. It is possible, therefore, to write an expression showing the amount within the lung at any time after cloud passage:

$$U = U_o \left[ae^{-\lambda_1 t} + be^{-\lambda_2 t} + ce^{-\lambda_3 t}\right], \qquad (3.1)$$

where

U_o = maximum amount of plutonium inhaled = 0.077 μc,*

U = maximum amount of plutonium in lung at any time in μc,

$a = 0.50\,\lambda_1 = \frac{0.693}{20} = 0.03465,$

$b = 0.15\,\lambda_2 = \frac{0.693}{180} = 0.00385,$

$c = 0.10\,\lambda_3 = \frac{0.693}{1} = 0.693.$

Equation 3.1 is plotted in Fig. 3.10 as lung burden in microcuries as a function of time after exposure to cloud passage. Lung burden decreases from initial burden of 0.058 μc to permissible lung burden of 0.02 μc in 38 days. Thus, the lung has an amount greater than a permissible burden for the first 38 days. After 38 days, the amount of plutonium in the lung would be less than the permissible burden.

*See WT-1510[8] and SC-4326(TR)[10] for variations with distance and with credible weather extremes climatologically.

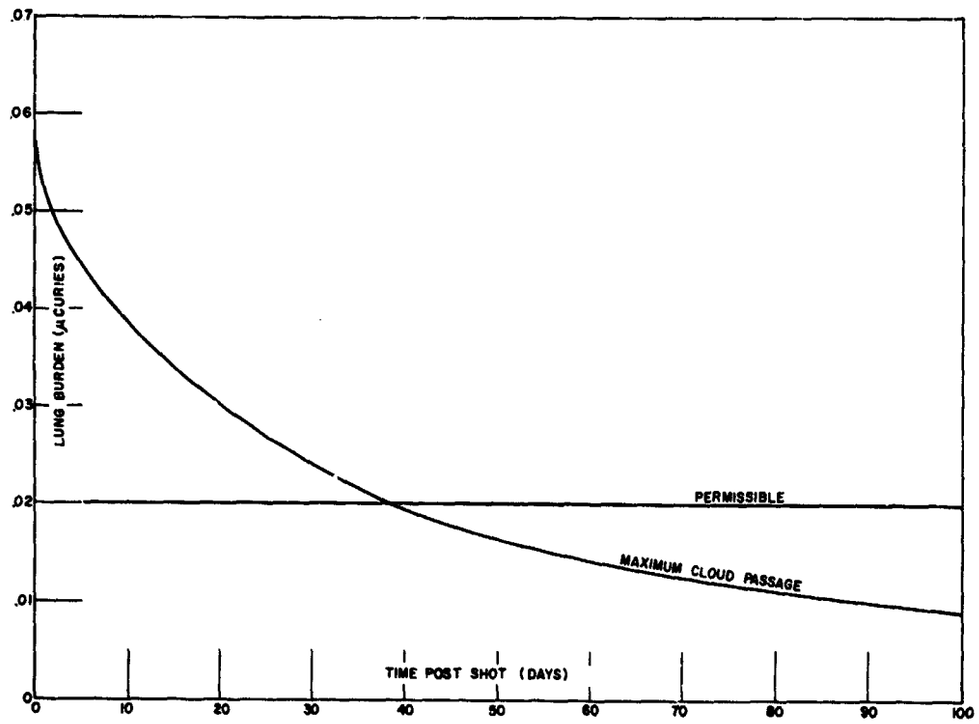


Fig. 3.10 -- Maximum amount of plutonium in lung from cloud passage as a function of time.

Since permissible lung burden is derived from allowing an exposure of 0.3 rem/week to the lung, cumulative exposure to the lung may be computed for both permissible body burden and body burden accumulated during cloud passage. Cumulative exposure in rem from a steady lung burden of 0.02 μc is simply 0.3 W, where W is the number of weeks of exposure. Cumulative exposure from plutonium deposited during cloud passage is determined by integration of Eq. 3.1 from t = 0 to t in order to obtain:

$$\text{Dose} = KU_o \left[\frac{a}{\lambda_1} \left(e^{-\lambda_1 t} - 1 \right) + \frac{b}{\lambda_2} \left(e^{-\lambda_2 t} - 1 \right) + \frac{c}{\lambda_3} \left(e^{-\lambda_3 t} - 1 \right) \right] . \qquad (3.2)$$

Where all constants are the same as in Eq. 3.1, except K, which is the conversion factor to give the dose in rem from exposure in μc-days and which is equal to 0.214.

Equation 3.2 is plotted in Fig. 3.11 as cumulative dose to lung in rem as a function of time in days. Figure 3.11 presents both cumulative dose from plutonium deposited during cloud passage and from the steady state burden of 0.02 μc. Cumulative cloud passage dose is greater than the dose from the steady state burden of

0.02 μc for times out to 103 days (14.7 weeks), where each dose is 4.4 rem. At times greater than 103 days, cumulative cloud passage dose is less for this example.*

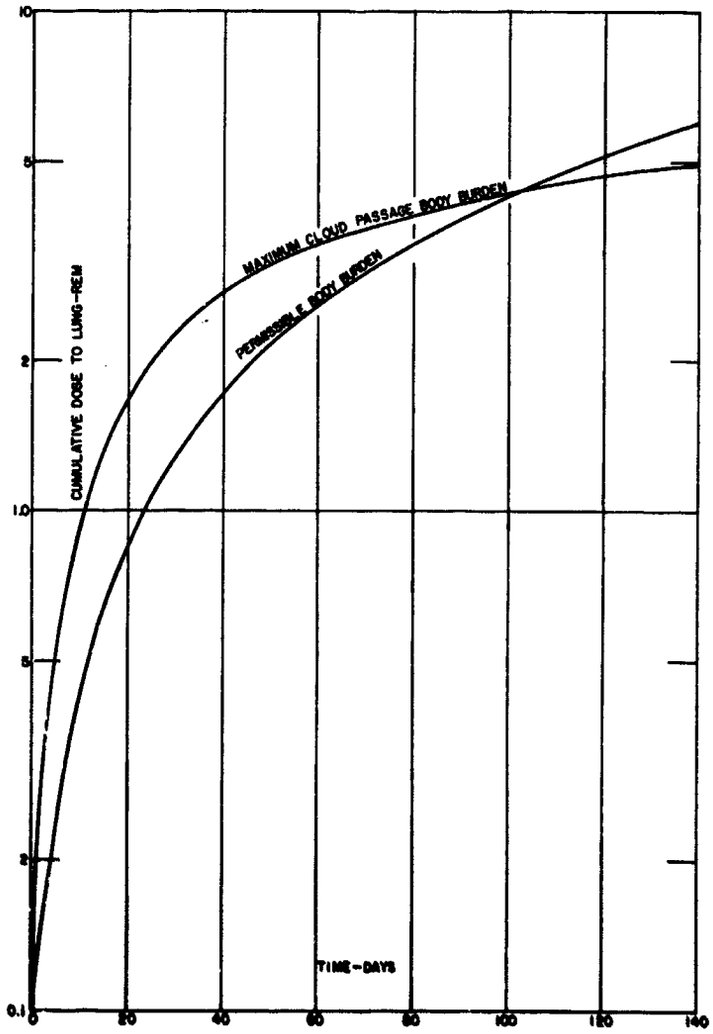


Fig. 3.11 -- Cumulative dose to lung from permissible body burden and maximum cloud passage body burden as a function of time.

It appears, from the specifics of (1) the actual TG-57 experimental condition of wind and (2) the explosion of one plutonium-bearing unit, that there was small average likelihood of a man accumulating a permissible lung burden at the 675-foot station of highest measured air concentration. Broader study of meteorological variations and the explosion of multiple units and their anticipated influence on hazards can be found in other reports.[8,10]

*See WT-1510[8] and SC-4326(TR)[10] for broader problem treatment.

3.8.2 Chronic Exposure

The continuous or chronic exposure problem is somewhat different from that of cloud passage, in that greater times are involved and air concentration is continually changing. To determine air concentration as a function of time, 11 Staplex air samplers (from 500 to 1000 feet north of ground zero) were run continuously until 31 days postshot. For all stations, plots of air concentration as a function of time after shot have the same shape, differing only in magnitude. Station 26.9 - 35.0, approximately 500 feet north of ground zero on the 1000 $\mu gm/m^2$ contour, was chosen as a typical station. A graph of air concentration at this station as a function of time after shot is presented in Fig. 3.12. In order to work with these data, a smooth curve was fitted to the experimental data by using two conditions: the area under the experimental curve (the total exposure to 31 days postshot) must be equal to the area under the smooth, fitted curve; initial air concentration of the fitted curve must be the same as experimental measurements at 0.1 day. The curve that best fitted the experimental data was found to be that curve defined by:

$$C = 0.141\ Co\ T^{-0.85}, \tag{3.3}$$

where

C = air concentration at any time T, in days postshot, and

Co = air concentration at 0.1 day, immediately after cloud passage.

A plot of this equation is shown in Fig. 3.12.

Since the item of most importance is the area under the air concentration curve, or total cumulative exposure, Fig. 3.13 compares total exposure as determined by the experimental and fitted curves. As can be seen from Fig. 3.13, the fitted power function curve overestimates hazard out to 8 days postshot, sometimes by as much as 68 percent. From 8 to 29 days, the fitted curve underestimates total exposure, but never by more than 16 percent. The fitted curve then again becomes the larger. Thus, Eq. 3.3 is a reasonable expression for air concentration as a function of time.

In order to determine permissible time of occupancy in an area contaminated with plutonium by an event similar to that of Project 57, Eq. 3.3 was used as the expression for dictating exposure to the lung from plutonium in the air. The lung model determined by Los Alamos[2] was used as the expression for removal of plutonium from the lung. By use of Eq. 3.3 and the Los Alamos lung model, the following equation was derived:

$$Co = \frac{Q_L}{24\ K\left[0.50\ e^{-\lambda_1 t}\int_{t_1}^{t_2} t^a e^{\lambda_1 t}\,dt + 0.15\ e^{-\lambda_2 t}\int_{t_1}^{t_2} t^a e^{\lambda_2 t}\,dt + 0.10\ e^{-\lambda_3 t}\int_{t_1}^{t_2} t^a e^{\lambda_3 t}\,dt\right]}, \tag{3.4}$$

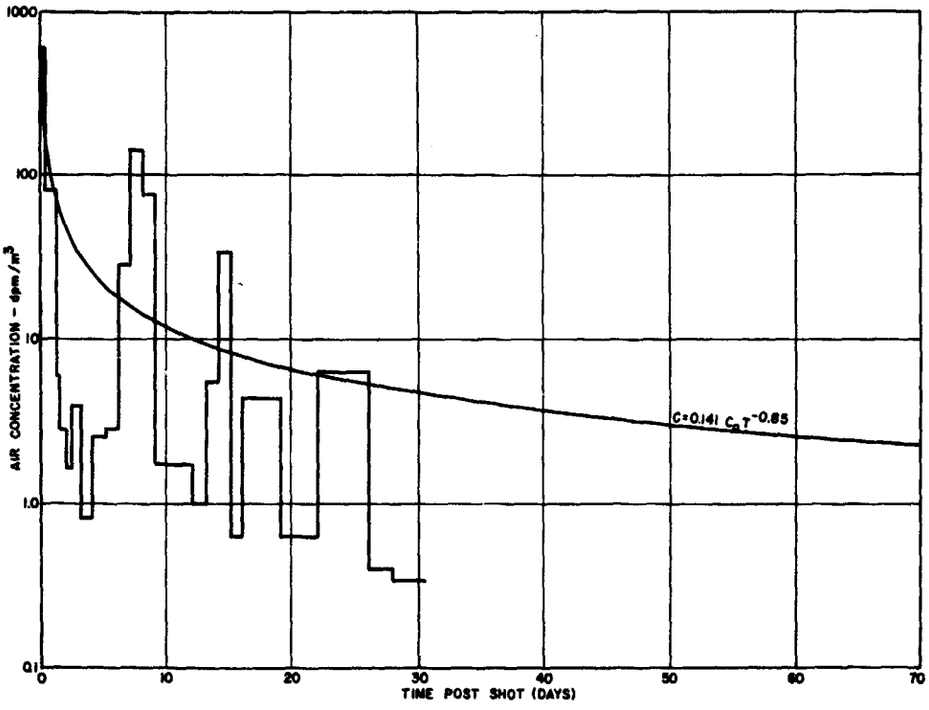


Fig. 3.12 -- Air concentration, experimental and fitted, as a function of time, Station 26.9 - 35.0.

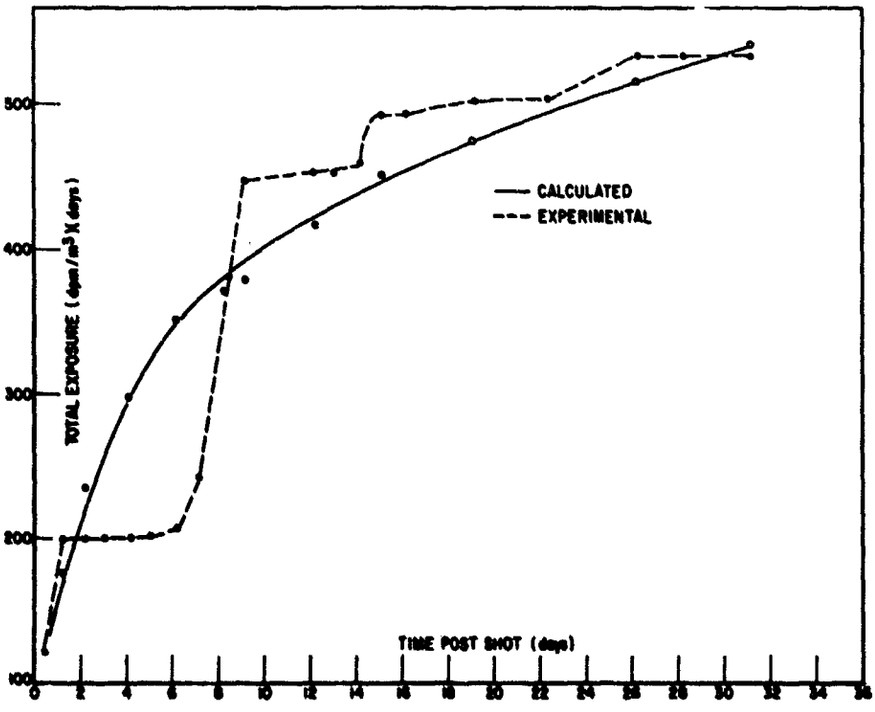


Fig. 3.13 -- Total exposure as a function of time from experimental and calculated air concentration curves.

where

C_o = initial (0.1 day) air concentration,

Q_L = amount of plutonium within the lung = 4.4×10^4 dpm,

t_1 = entrance time in days postshot,

t_2 = exit time in days postshot,

K = constant from Eq. 3.3 = 0.141,

a = constant from Eq. 3.3 = 0.85

= removal constant from #1 compartment of the lung = $\frac{0.693}{20}$

= removal constant from #2 compartment of the lung = $\frac{0.693}{180}$

= removal constant from #3 compartment of the lung = $\frac{0.693}{1}$

Derivation of this equation and an explanation of the Los Alamos Lung Model are contained in Appendix A.

Use of Eq. 3.4 and substitution of various times for entry time and exit time provide a system of curves showing permissible initial (0.1 day) air concentration as a function of time of occupancy for six different entrance times. These curves are presented in Fig. 3.14. It should be noted that the left-hand ordinate in this illustration is in dpm/m^3 and, while the right-hand ordinate is of the same magnitude as the left, it is in units of $\mu gm/m^2$. This may be done in this manner, since the average of the ratio of air concentration in dpm/m^3 to soil concentration in $\mu gm/m^2$ for 11 stations at 0.1 day was 1. Thus, permissible time of occupancy as a function of soil concentration for various entrance times can be read from Fig. 3.14.* Since the left ordinate is in dpm/m^3 at 0.1 day, it is important, therefore, that air concentrations on subsequent days be extrapolated to that time. Table 3.11 shows permissive time of occupancy for various entry times and ground concentration levels. Figure 3.15 is a graph of air concentration degradation factors as a function of time postshot. To obtain conditions of 0.1 day, readings of any later time are multiplied by the degradation factor corresponding to that time (determined by repeated alpha counter surveys). Results of this exercise must be considered rough approximations. Longer term measurements by Programs 71 and 72* provide more actual and complete data on this subject. In those studies also, the hazard was of the order forecast here.

Thus, within the resuspension force restrictions noted, it appears that a person entering a contaminated area 3 hours or more after detonation could go to the 5000 $\mu gm/m^2$ contamination contour and live a lifetime without accumulating a permissible body burden of plutonium. If time of entry into the field is delayed, a human might remain longer at a higher concentration.

*See WT-1510[8] and SC-4326(TR).[10]

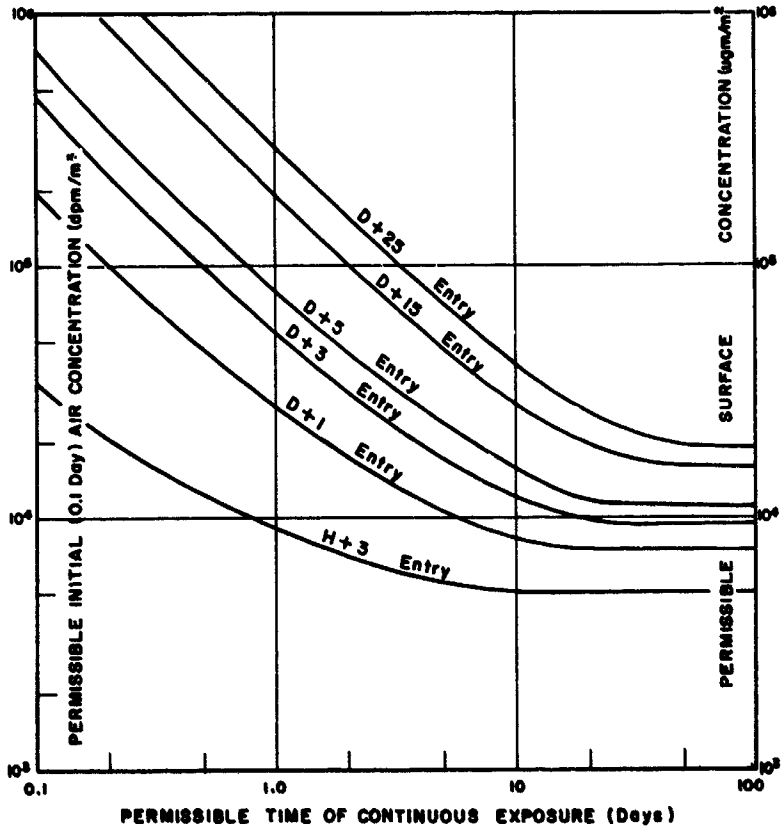


Fig. 3.14 -- Permissible air and surface concentrations as a function of continuous exposure time for normal wind action. It should be noted that curves are not applicable when digging or other mechanical resuspension is likely.

TABLE 3.11 -- PERMISSIBLE TIME OF OCCUPANCY FOR VARIOUS ENTRANCE TIMES AND GROUND CONCENTRATION LEVELS*

Ground concentration ($\mu gm/m^2$)	Permissib. time of occupancy (days)			
	(3-hour entry)	(1-day entry)	(3-day entry)	(5-day entry)
1,000	Lifetime	Lifetime	Lifetime	Lifetime
3,500	Lifetime	Lifetime	Lifetime	Lifetime
5,000	Lifetime	Lifetime	Lifetime	Lifetime
6,000	4 days	Lifetime	Lifetime	Lifetime
8,000	1.5 days	11 days	Lifetime	Lifetime
10,000	0.8 day	5.8 days	18 days	Lifetime
15,000	0.35 day	2.5 days	6.2 days	10 days
25,000	0.15 day	1.1 days	2.8 days	4.4 days
50,000	--	0.45 day	1.1 days	1.7 days
100,000	--	0.21 day	0.5 day	0.75 day

*With no suspension other than by normal winds.

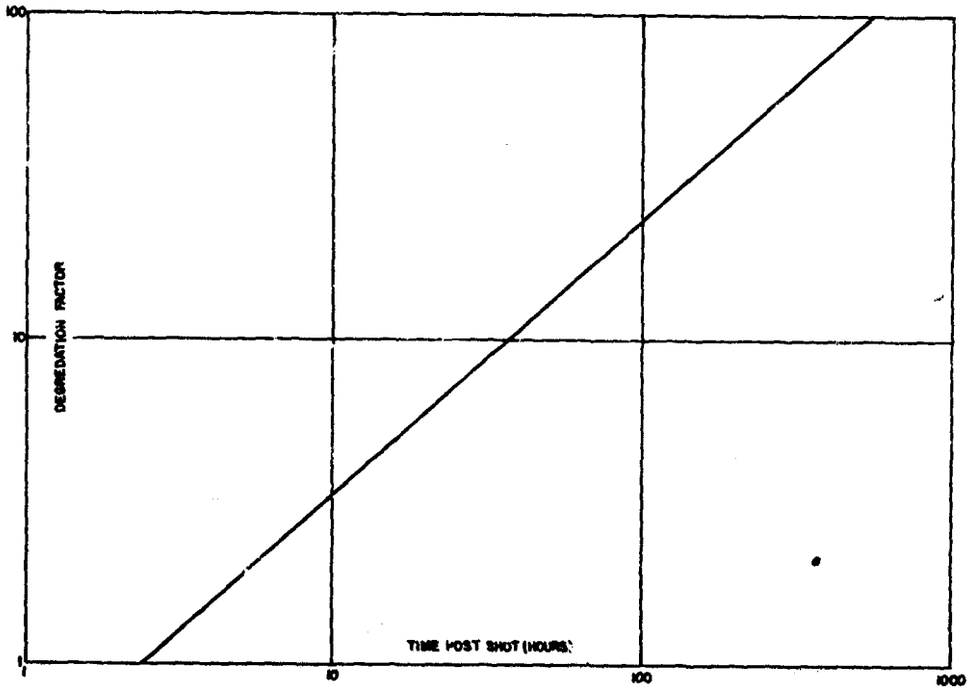


Fig. 3.15 -- Air concentration degradation factors as a function of time.

Another method of estimating the chronic hazard problem is to examine gas mask canisters worn by people working in the area. Each person wore the same canister assigned to him for the entire time spent within the area during the test period. Since urinalysis on persons concerned indicated no plutonium within the body, it is assumed that gas mask canisters stopped and retained all plutonium in the air breathed by these persons. Table 3.12 gives data from the gas mask canisters.

TABLE 3.12 -- GAS MASK CANISTER DATA

	Content (μgm)	Fraction of a permissible body burden (percent)	Time in area (days)
Person A	0.273	0.84	25
Person B	0.261	0.81	8
Person C	0.198	0.61	26
Person D	0.169	0.52	3

All persons entered the field within 2 hours after detonation and stayed for approximately 8 hours that day. The other days, approximately 6 to 7 hours were spent in the field, all within 1000 feet of ground zero.

Person D spent his time in the area on D-day extensively monitoring soil from 1000 feet north of ground zero into the lip of the crater at ground zero. In doing this, Person D spent a considerable amount of time with his breathing zone 2 to 3 feet above ground where very high concentrations of plutonium existed. Person D was also exposed to the visible cloud from the active resuspension on D+2 which gave very high air concentrations.

Person B was in the area daytimes from D-day to D+7. During this period he was exposed to many resuspensions, and was directly in the cloud on three occasions.

Persons A and C have similar time histories in the contaminated area except that on D-day, Person C was changing air samplers and cascade impactors while Person A was monitoring soil. Thus the latter was closer to the ground surface on that day. Persons A and C each drove the jeep in 12 resuspensions. While driving this open vehicle, they were subjected to the highest possible air concentrations. The dust cloud containing plutonium was extremely dense and left the clothing of the driver darkened. All resuspensions were accomplished within the 100 $\mu gm/m^2$ contour and several were done within the 1000 $\mu gm/m^2$ contour, giving air concentrations of 104 dpm/m^3 and higher.

Thus it is obvious that no canister picked up a quantity equal to a permissible body burden, even when the person wearing the mask and canister was subjected to extremes of air concentrations. It should be remembered also that the canisters captured and retained the plutonium and that there was no elimination from the canisters as there is from the lung.

Should a detonation similar to that of Test Group 47 take place in a geographical location where there is a grass cover on the ground, chronic exposure hazard might be considerably reduced. As was noted earlier, grass tends to trap plutonium particulate and to hold it tenaciously, thus decreasing the degree of resuspension and thereby decreasing airborne concentration. From the standpoint of resuspension by wind, conditions at the Nevada Test Site tend to maximize air concentration caused by strong winds which easily lift the dry, barren topsoil.

Chapter 4

CONCLUSIONS AND RECOMMENDATIONS

1. For hard surfaces, high-pressure water hosing exhibited an average efficiency of 96 percent and should be the easiest and cheapest method of decontamination. Caution with runoff water disposal is an obvious requirement.

2. For land areas, plowing and oiling are the two methods of decontamination that are easiest and cheapest. As a temporary measure, covering the area with water or fire-fighting foam will be 90-percent effective for a period up to 1 hour.

3. Sample calculations of the probable acute radiological hazard to man were made from air samples collected 675 feet north of ground zero during cloud passage. With assumptions of one-time exposure to this environment, median biological response, and validity of the Los Alamos lung model,[3] results were as follows:

   a. Initial lung deposition would have been approximately three times the maximum permissible level (mpl) of continuous lung burden (0.02 μc).

   b. With the three-compartment clearance the Los Alamos lung model describes, lung burden could be expected to reduce to the mpl in about 40 days.

   c. Integrated lung dose would approach that produced by continuous irradiation at mpl after roughly 105 days.

4. Sample calculations of the approximate chronic radiological hazard to man were made from 31 days of postshot air sampling at 500 feet north of ground zero and extrapolation of these data to longer times. If an orderly and constant relation of air concentration to ground deposition of plutonium is assumed (certainly unproven here), rough estimates of permissible time of occupancy as a function of deposition level and time delay of entrance can be developed. It appeared that with entry to the area after H+3 hours, unlimited occupancy could be tolerated at the 5000 $\mu gm/m^2$ deposition contour, provided there were no natural or other resuspension forces greater than those which prevailed for the 31 days of actual air sampling. This is an interesting but very provisional set of results. From these estimates it is recommended that decontamination, certainly to ≤ 1000 $\mu gm/m^2$, be accomplished for any real accident area. For complete rehabilitation, much more complete decontamination would be needed.

REFERENCES

1. Cowan, M., and Kingsley, W. H.; Contamination from One-Point Detonations, TM-272-55-51, Sandia Corporation, August 1956; SRD.

2. Johnson, W. S.; Report on Fallout Study of January 1956-57 Project, NTS, LAMS 2033, Los Alamos Scientific Laboratory, June 1, 1957; CRD.

3. Harris, P. S., Anderson, E. D., and Langham, W. H.; Contamination Hazard from Accidental Noncritical Detonation of Small Atomic Devices, LA-2079, Los Alamos Scientific Laboratory, September 1956; SRD.

4. Boeker, B. B., and Dick, J. L.; Effects of Plutonium Contamination on Air Force Installations, TN-56-64, Air Force Special Weapons Center, March 1957; SRD.

5. Baker, T. P., and Dick, J. L.; Effects of Plutonium Contamination on Air Force Operations (Revised), TN-57-40, Air Force Special Weapons Center, December 1958; SRD.

6. Baker, T. P., and Dick, J. L.; Aircraft Accidents Involving Plutonium Contamination, TN-58-3, Air Force Special Weapons Center, May 1958; U.

7. Merian, R. F., and O'Loughlin, J.; Evaluation of Portable Alpha Survey Instruments, AFSWC-TR-57-40, Air Force Special Weapons Center, December 1957; U.

8. Cowan, M. Jr.; Plutonium Contamination from One-Point Detonation of an XW-25, WT-1510, Sandia Corporation, November 1960; SRD.

9. Butler, R. E., and Miller, H. M.; Surface Alpha Monitoring as a Method of Measuring Plutonium Fallout, WT-1513, Sandia Corporation, August 1961; U.

10. Merritt, M. L., Cowan, M., Reed, J. W., and Shreve, J. D.; Airborne Plutonium from Weapon Accidents, SC-4326(TR), Sandia Corporation, July 1959; SRD.

Appendix A

DERIVATION OF TIME OF OCCUPANCY EQUATION

From the two stations 500 feet north of ground zero, decrease in airborne plutonium was best fitted by a power function curve, i.e., $C = K\,Co\,t^{a}$.

Therefore, if a breathing rate of 1 m^3/hr is assumed, $N = 24\,Co\,K\,t^{a}$ is a rate (dpm/day) of body exposure, where Co is the initial air concentration.

Let Q be the amount (dpm) in the lung, and let Q be the rate (dpm/day) of Pu exhaustion from the lung.

Then the rate of change of Pu in the lung is given by:

$$\frac{dQ}{dt} = 24\,Co\,Kt^{a} - \lambda Q,$$

or

$$\frac{dQ}{dt} + \lambda Q - 24\,Co\,Kt^{a} = 0.$$

This is a standard linear differential equation whose general solution is:

$$Q = 24\,KCo\,e^{-\lambda t}\int_{b}^{d} t^{a} e^{\lambda t}\,dt. \qquad \text{(A. 1)}$$

Using the lung model,[2] of an original 100 particles inhaled, 25 are exhaled immediately without deposition. Of the 75 particles deposited in the lung, 50 are deposited in the upper bronchial tree and are eliminated by ciliary action with a half-time of 20 days. The remaining 25 particles are assumed to be deposited on the alveolar surfaces. Since the particles concerned are insoluble, 15 are phagocytized or otherwise carried up the bronchial tree with a half-time of 180 days and swallowed and eliminated. The remaining 10 particles pass through the alveolar wall into the blood with a half-time of about one day.

There are, therefore, three compartments for exhaustion from the lung:

$$\lambda_1 = \frac{0.693}{20},\ 0.50,$$

$$\lambda_2 = \frac{0.693}{180},\ 0.15,$$

$$\lambda_3 = \frac{0.693}{1},\ 0.10.$$

The specific solution for the three compartments of the lung of Eq. A. 1 is:

$$Q_L = 24\,K\,Co\left[0.50\,e^{-\lambda_1 t}\int_{t_1}^{t_2} t^a e^{\lambda_1 t}\,dt + 0.15\,e^{-\lambda_2 t}\int_{t_1}^{t_2} t^a e^{\lambda_2 t}\,dt + 0.10\,e^{-\lambda_3 t}\int_{t_1}^{t_2} t^a e^{\lambda_3 t}\,dt\right]. \qquad \text{(A. 2)}$$

The two stations 500 feet north of ground zero which sampled air continuously for 31 days postshot under natural weather resuspension is best fitted by the power curve:

$$C = 0.141\,Co\,t^{-0.85}.$$

Therefore, in Eq. A. 2 K = 0. 141 and a = -0. 85.

Using Q_L = permissible body burden for plutonium = 4.4×10^4 dpm, Eq. A. 2 may be solved for Co, the initial air concentration.

Appendix B

NECESSARY TIME DELAY FOR COUNTING ALPHA AIR SAMPLES

B. 1 BACKGROUND

Recent developments have made it imperative that a quick and reliable method be determined for assessment of airborne alpha contamination. Collection and interpretation of alpha air samples is complicated by the fact that there are naturally occurring alpha emitters in the atmosphere which decay with short half-lives such as Ra C $\xrightarrow{19.7m}$ Ra D and Th C $\xrightarrow{60.5m}$ Th D. When looking for long-lived alpha emitters, it is customary to allow a 24- to 72-hour period before counting, to allow this natural activity to decay away to insignificance. Since a 24- to 72-hour delay is not practical in the field, this appendix demonstrates the effects of earlier counting of the sample and the errors involved.

B. 2 PROCEDURE

A one-hour sample was colle ed on each of twelve mornings at Kirtland Air Force Base with a Staplex High Volume Sampler having 4-inch disks of MSA 1106-B glass fiber filter paper. These samples were counted immediately after collection and at other selected intervals until activity decayed to zero. Counts per minute of these samples were converted to disintegrations per minute per cubic meter of air by use of the following equation:

$$\text{dpm/m}^3 = \frac{\text{counts per minute x two (self absorption)}}{\text{percent efficiency of counter x flow rate of sampler x time of sampling}}.$$

Alpha activity in dpm/m^3 indicated by these samples was then plotted as a function of time after collection (Fig. B. 1).

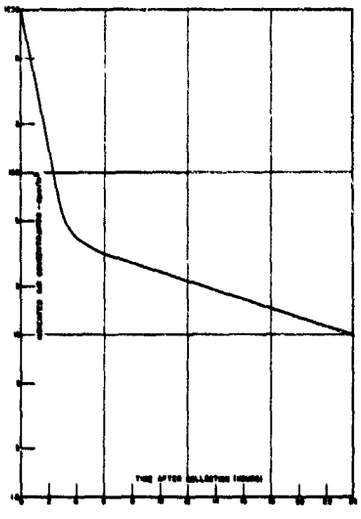


Fig. B. 1—Indicated alpha activity.

B. 3 RESULTS

Results of this experiment are shown in Table B. 1. The "initial cpm" values are count rates at two minutes after collection, and "initial dpm/m^3" values are those calculated from the "initial cpm" values. The terms "4-hour," "15-hour," and "24-hour" refer to times after sampling at which the samples were counted.

TABLE B. 1—NATURAL ALPHA ACTIVITY

Date 1957	Initial (c/m)	Initial (dpm/m^3)	4-hour (c/m)	4-hour (dpm/m^3)	15-hour (c/m)	15-hour (dpm/m^3)	24-hour (c/m)	24-hour (dpm/m^3)
3 Sep	1000	210	270	58	68	15	50	10.5
4 Sep	7100	1500	320	68	148	31	67	14.5
5 Sep	3850	810	135	28	64	14	37	8.0
6 Sep	4900	1050	220	46	99	21	54	11.5
9 Sep	4900	1050	190	40	83	18	44	9.4
10 Sep	1650	350	94	20	44	9.4	24	5.0
10 Sep	900	190	19	40	12	2.5	9	1.9
11 Sep	2250	480	115	25	52	11	29	6.2
12 Sep	6500	1380	240	50	99	21	51	10.8
13 Sep	6300	1350	330	70	135	29	70	15.0
16 Sep	4900	1050	190	40	78	17	40	8.4
17 Sep	2320	500	97	21	43	9.4	23	4.8

B. 4 DISCUSSION AND RECOMMENDATIONS

From Table B. 1, counting the sample at four hours after collection gives an indicated dpm/m^3 due to natural alpha activity of 50±30. Where air concentrations of long-lived alpha emitters on the order of 100 to 1000 dpm/m^3 in an emergency situation are considered, four hours is a sufficient delay between collection and counting of the sample. By subtracting 50 dpm/m^3 from results of the four-hour counting data, sufficient accuracy is maintained for the emergency situation. If the long-lived alpha air concentration is of the order of 1000 dpm/m^3, the data indicate a maximum error of 3 percent and a maximum error of 30 percent for air concentrations around 100 dpm/m^3. This error is not too great to preclude counting at this time in order to obtain an estimate of air concentration in a given area.

Because of the importance of establishing the air concentration as early as possible and the small error involved by subtracting 50 dpm/m^3 from the ascertained air concentration, it is recommended that all filter samples be counted at four hours in air emergency situations so that immediate action can be taken. Refinements of these original values can be made by repeated counting at 72 hours if desired.

B. 5 LIMITATIONS

Due to the necessary brevity of this experiment, results are subject to many limitations. Table B. 1 indicates that the original activity levels varied from 190 to 1380 dpm/m^3 on the 12 days of sampling. How activity levels vary with meteorological conditions and geographical location is not known. It is expected that natural alpha activity in New Mexico would probably represent higher values than many other parts of the United States.

The discussion here is applicable only to high-volume samples taken on MSA 1106-B glass filter paper. At a low-volume sampling rate, or with different type filter paper, various particle sizes may be retained, leading to dissimilar results.

As time and facilities permit, research will be continued to ascertain effects of geographical location, meteorological conditions, filter paper, and sampling rate.

Appendix C

SURFACE MONITORING DATA

Results of shot-day monitoring are contained in Table C. 1. Readings in excess of 100, 000 cpm, the highest reading possible on an unaltered PAC-1G, are omitted.

Tables C. 2 and C. 3 contain raw data from time-study monitoring for pads and soil surfaces.

TABLE C. 1—D-DAY METER READINGS

Surface	Station	Mean cpm
Soil	25. 8-36. 6	48, 750
Asphalt	25. 8-37. 4	67, 700
Asphalt	26. 3-36. 6	95, 000
Tarpaper	26. 7-31. 0	44, 750
Unpainted wood	26. 7-31. 2	76, 000
Brick	26. 7-31. 6	85, 250
Soil	26. 7-31. 8	75, 250
Soil	26. 7-34. 6	98, 000
Galvanized roofing	26. 7-35. 6	88, 000
Soil	26. 7-36. 0	58, 750
Brick	26. 7-36. 4	74, 250
Stucco	26. 7-36. 6	78, 000
Asbestos shingle	26. 7-36. 8	77, 250
Wood shingle	26. 7-36. 8	71, 500
Painted wood	26. 7-37. 0	91, 750
Concrete	26. 7-37. 2	90, 000
Asphalt	26. 7-37. 4	68, 750
Steel	26. 7-37. 6	55, 500
Aluminum	26. 7-37. 8	54, 250
Galvanized roofing	26. 7-38. 0	40, 250
Tarpaper	26. 7-38. 2	72, 000
Unpainted wood	26. 7-38. 4	67, 000
Glass	26. 7-38. 6	62, 500
Brick	26. 7-38. 8	63, 250
Stucco	26. 7-39. 0	43, 500
Concrete	27. 3-38. 2	52, 500
Asphalt	27. 3-37. 4	27, 000
Concrete	27. 3-36. 6	63, 400
Soil	27. 3-36. 6	47, 250
Asphalt	27. 3-35. 8	70, 600
Asphalt	27. 3-35. 0	50, 000
Soil	27. 3-35. 0	44, 750
Asphalt	27. 3-33. 4	89, 200
Grass	27. 7-31. 0	17, 000
Concrete	27. 7-31. 2	65, 500
Grass	27. 7-31. 4	12, 000

TABLE C. 1—D-DAY METER READINGS (CONTINUED)

Surface	Station	Mean cpm
Asphalt	27.7-31.6	82, 750
Grass	27.7-31.8	31, 500
Grass	27.7-32.2	54, 750
Soil	27.7-32.2	87, 500
Grass	27.7-32.6	40, 000
Grass	27.7-33.0	36, 000
Grass	27.7-33.4	28, 750
Grass	27.7-33.8	41, 250
Soil	27.7-34.0	42, 000
Grass	27.7-34.2	28, 500
Grass	27.7-34.6	17, 750
Asphalt	27.7-34.8	69, 750
Concrete	27.7-35.0	57, 750
Asphalt	27.7-35.2	62, 500
Grass	27.7-35.4	10, 750
Concrete	27.7-35.6	57, 000
Grass	27.7-35.8	13, 250
Asphalt	27.7-36.0	61, 000
Grass	27.7-36.2	16, 000
Concrete	27.7-36.4	47, 750
Soil	27.7-36.4	29, 500
Grass	27.7-36.6	8, 250
Asphalt	27.7-36.8	36, 750
Grass	27.7-37.0	6, 500
Concrete	27.7-37.2	33, 500
Grass	27.7-37.4	7, 750
Asphalt	27.7-37.6	32, 500
Grass	27.7-37.8	8, 000
Concrete	27.7-38.0	31, 500
Grass	27.7-38.2	6, 750
Asphalt	27.7-38.4	30, 500
Grass	27.7-38.6	5, 500
Concrete	27.7-38.8	30, 000
Grass	27.7-39.0	2, 250
Soil	28.3-34.2	42, 500
Asphalt	28.3-34.2	52, 700
Concrete	28.3-35.0	28, 350
Concrete	28.3-35.8	53, 000
Asphalt	28.3-36.6	30, 400
Soil	28.3-37.4	20, 750
Concrete	28.3-37.4	33, 500
Asphalt	28.3-38.2	25, 200
Asphalt	28.7-33.6	90, 500
Galvanized roofing	28.7-34.2	74, 500
Tarpaper	28.7-34.4	63, 250
Unpainted wood	28.7-34.6	61, 000
Glass	28.7-34.8	52, 500
Soil	28.7-31.2	28, 350
Soil	28.7-33.0	27, 000
Soil	28.7-34.6	15, 000
Brick	28.7-35.0	46, 000
Stucco	28.7-35.2	48, 000
Wood shingle	28.7-35.4	42, 750
Asbestos shingle	28.7-35.4	43, 250
Painted wood	28.7-35.6	37, 000
Concrete	28.7-35.8	33, 250
Asphalt	28.7-36.0	37, 500

TABLE C. 1—D-DAY METER READINGS (CONTINUED)

Surface	Station	Mean cpm
Steel	28.7-36.2	23,750
Aluminum	28.7-36.4	27,000
Galvanized roofing	28.7-36.6	18,750
Tarpaper	28.7-36.8	47,750
Unpainted wood	28.7-37.0	46,750
Glass	28.7-37.2	33,000
Brick	28.7-37.4	48,250
Stucco	28.7-37.6	40,250
Wood shingle	28.7-37.8	49,750
Asbestos	28.7-37.8	46,750
Painted wood	28.7-38.0	49,500
Concrete	28.7-38.2	44,250
Asphalt	28.7-38.4	46,250
Steel	28.7-38.6	52,250
Aluminum	28.7-38.8	41,500
Galvanized roofing	28.7-39.0	26,000
Soil	29.3-31.0	50,000
Asphalt	29.3-31.8	80,400
Asphalt	29.3-33.4	61,300
Soil	29.3-33.4	34,500
Concrete	29.3-34.2	41,500
Asphalt	29.3-35.0	33,800
Concrete	29.3-35.8	48,400
Soil	29.3-35.8	31,750
Asphalt	29.3-36.6	41,600
Concrete	29.3-37.4	47,900
Asphalt	29.3-38.2	34,200
Concrete	29.3-39.0	43,500
Concrete	29.7-31.0	76,250
Asphalt	29.7-31.2	91,000
Asphalt	29.7-31.6	88,250
Galvanized roofing	29.7-32.2	73,500
Tarpaper	29.7-32.4	92,500
Unpainted wood	29.7-32.6	77,500
Glass	29.7-32.8	78,250
Brick	29.7-33.0	59,500
Stucco	29.7-33.2	59,750
Wood shirgle	29.7-33.4	51,750
Asbestos shingle	29.7-33.4	48,500
Painted wood	29.7-33.6	54,000
Concrete	29.7-33.8	47,000
Asphalt	29.7-34.0	49,250
Steel	29.7-34.2	47,250
Soil	29.7-34.2	31,750
Aluminum	29.7-34.4	42,750
Galvanized roofing	29.7-34.6	25,250
Tarpaper	29.7-34.8	39,250
Soil	29.7-34.6	30,250
Unpainted wood	29.7-35.0	47,250
Glass	29.7-35.2	50,500
Brick	29.7-35.4	44,000
Stucco	29.7-35.6	46,500

TABLE C.2—PAD MONITORING AS A FUNCTION OF TIME

Surface	Station	D-day	Mean meter readings in cpm											
			D+1	D+2	D+3	D+4	D+7	D+12	D+22	D+26	D+90	D+180	D+365	D+550
Tarpaper	29.7-32.4	92,500	66,750	80,625	81,250	75,500	65,840	28,750	19,500	12,500	579	5,000	2,850	4,000
Asphalt	29.3-33.4	61,300	51,300	62,250	66,800	49,800	22,800	11,800	6,480	8,625	1,375	2,400	720	1,100
Stucco	28.7-32.8	97,000	67,000	75,000	29,500	35,500	31,250	32,500	6,150	9,000	529	6,325	3,550	3,000
Painted wood	28.7-35.6	37,000	49,000	14,375	11,800	8,375	3,750	1,050	544	250	200	135	72	106
Plate steel	28.7-38.6	52,250	13,750	11,875	15,500	7,825	5,625	1,560	1,063	556	231	170	90	100
Concrete	28.3-35.8	53,000	24,000	26,000	29,900	16,600	---	15,000	2,430	475	1,910	1,513	1,275	1,050
Concrete	27.7-33.6	100,000	71,875	75,000	65,500	65,600	53,750	38,500	5,875	1,938	3,788	5,250	3,830	3,280
Grass	27.7-35.8	13,250	11,000	7,060	7,560	1,125	2,125	1,225	631	---	719	663	665	625
Asphalt	27.7-38.4	30,500	---	20,625	19,500	12,500	8,125	11,000	1,225	975	538	1,575	2,025	1,720
Concrete	27.3-32.6	100,000	30,000	91,250	82,800	73,000	---	---	10,810	9,300	6,005	6,760	4,500	4,500
Glass	26.7-31.4	100,000	19,500	23,750	24,500	6,240	5,200	1,150	500	125	198	93	55	20
Aluminum	26.7-33.0	100,000	78,500	100,000	100,000	60,625	---	18,150	1,650	1,494	800	615	394	310
Unpainted wood	26.7-38.4	67,000	46,250	50,000	47,400	23,800	3,225	30,000	22,000	15,000	11,000	7,225	6,812	---
Galvanized roofing	26.7-35.6	87,500	29,000	30,000	24,000	10,800	---	2,550	575	2,563	928	118	365	200
Concrete	26.3-34.6	100,000	93,250	93,800	90,000	---	---	24,000	---	4,750	1,613	400	375	1,100
Asphalt	26.3-35.0	100,000	77,750	86,250	82,750	---	---	1,525	19,750	13,125	5,313	6,340	8,900	6,800
Asphalt	25.8-37.4	67,700	13,500	43,000	41,600	22,500	---	20,500	2,910	2,400	2,690	3,660	2,225	1,500
Wood shingle	29.7-35.8	33,500	23,500	15,625	---	24,000	2,500	---	6,988	8,438	3,000	7,975	4,225	4,750

END 6-9

TABLE C. 3—SOIL MONITORING AS A FUNCTION OF TIME

Station	D-day	Mean meter readings in cpm										
		D+2	D+3	D+4	D+7	D+12	D+22	D+26	D+90	D+180	D+365	D+550
29.7-32.4	30,250	17,500	11,125	10,625	3,250	1,940	775	1,375	244	228	102	125
29.7-35.2	31,750	---	5,075	1,000	---	625	269	450	121	220	12	112
29.3-32.6	34,500	18,500	8,275	8,650	---	1,460	956	1,688	219	865	126	94
29.3-35.4	31,750	---	---	7,500	---	---	---	1,550	381	550	126	---
28.7-32.8	27,000	20,500	3,400	3,200	4,875	1,937	863	581	250	595	190	180
28.7-35.6	15,000	6,250	6,025	590	---	2,440	363	294	569	130	212	112
28.3-32.6	---	11,500	1,250	415	---	1,562	638	113	375	238	180	175
28.3-35.8	42,500	15,000	8,600	7,000	---	3,190	600	206	1,100	270	122	130
27.7-33.2	---	28,500	1,975	---	1,850	---	3,100	306	988	1,543	495	437
27.7-36.0	40,000	33,000	1,900	3,000	1,660	2,300	950	2,188	975	1,750	230	220
27.3-33.4	44,750	16,500	13,825	6,500	---	2,550	1,013	1,438	1,150	1,213	---	530
27.3-33.6	47,250	10,670	2,025	5,000	362	2,500	1,050	1,988	1,050	1,003	---	---
26.7-33.6	98,000	17,000	23,625	8,250	3,125	4,825	2,025	3,000	1,725	1,548	220	560
26.7-36.2	58,750	11,125	---	4,125	2,150	1,500	775	675	663	180	116	180
26.3-33.8	---	48,500	31,000	11,250	7,500	5,700	4,125	1,563	2,325	1,275	612	950
26.3-36.2	---	12,250	3,470	---	---	---	538	---	631	188	---	225
25.8-34.2	100,000	100,000	100,000	65,000	47,750	55,625	32,750	6,800	1,688	1,675	5,575	2,450
25.8-37.4	48,750	29,000	9,725	13,750	---	5,375	2,150	450	2,425	900	237	487